One Side Welding—Flux Development—and Study of Multiple Arc Behavior

Project Report by Bethlehem Steel Corporation
in cooperation with U. S. Maritime Administration

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FOREWORD

The purpose of this report is to present the results of one of the research and development programs which was initiated by the members of the Ship Production Committee of The Society of Naval Architects and Marine Engineers and financed largely by government funds through a cost sharing contract between the U.S. Maritime Administration and Bethlehem Steel Corporation. The effort of this project was directed to the development of improved methods and hardware applicable to shipyard welding in the U.S. shipyards,

Mr. W. C. Brayton, Bethlehem Steel Corporation was the Program Manager, Mr. G. D. Uttrachi, Linde Division of Union Carbide Corporation, was the Senior Project Engineer who provided the technical direction. The work was performed at the Union Carbide Research Facility at Tarrytown, New York.

Special acknowledgement is made to the members of Welding Panel SP-7 of the SNAME Ship Production Committee who served as technical advisors in the preparation of inquiries and evaluation of sub-contract proposals.

EXECUTIVE SUMMARY

BACKGROUND

The technique of one-side welding is not new in the United States. There have been numerous successful shipyard applications involving plates up to 3/4" thick. The higher currents and the resulting larger pool of molten metal necessary for single pass welding of thicker plating impose flux requirements which can not be met by conventional American or European fluxes.

Several methods have been used in Japan during the development of one-side welding over the past few years. The method most widely used at present is the FCB (Flux Copper Backing) process and the flux developed under this project was for use with this process.

In addition. to the flux problem the proper control of arc behavior with separately powered multiple arcs was also a problem of significance. Although the flux development and the arc behavior study were identified as separate projects they were awarded to the same subcontractor and performed concurrently.

OBJECTIVES

A. FLUX DEVELOPMENT

Develop a submerged arc welding flux or fluxes capable of making satisfactory butt welds in steel plates ranging from ½" to 1½" in thickness from one side of the plates in a single pass using multiple arc welding systems.

B. ARC BEHAVIOR STUDY

Investigate various power supply connections and electrode configurations for submerged arc welding employing as many' as four (4) separately powered arcs of as much as 1500 Amps. per electrode.

Determine the operating parameters which provide the best consistent performance for one-side welding with-in the current range which will produce travel speeds of 25-30 I.P.M. on 1½" thick plates.

ACHIEVEMENT

The parallel effort of developing a one-side welding flux and a set of operating parameters was successfully accomplished. Welds of comparable quality, appearance and speed to the best of those observed in Japan were made both in the Union Carbide laboratory and in several shipyards.

Sample batches of the flux have been made in a pilot plant for qualification tests.

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Report No. 1

Project SP-1-l Part 101
Contract No. 1560-721-l511-S/02-3764-D
One Side Welding Flux Development

Program Objective

Presently available domestic submerged arc welding fluxes do not have the proper operating characteristics to produce one side welds of acceptable quality in heavy plate in ship fabrication. These fluxes also do not provide adequate impact resistance in heavy welds.

The objective of this program is to produce a flux suitable for manufacturing in the U.S. which, in conjunction with the multiwire system described in SP-101 Item 102, will provide satisfactory quality one side welds in 1 1/2 inch thick plate at speeds of 25-30 ipm and 50-60 ipm on thinner plate. When combined with a suitable wire, the mechanical properties of the weld joints must meet all requirements for ABS grades of carbon steel.

FIRST QUARTER GOALS:

The goals for the first quarter of this program are as follows:

1. Process and evaluate a series of fluxes selected from several flux systems in order to establish potential flux formulae which have the performance capabilities of producing one side welds.

2. Verify the existing foreign welding techniques using foreign fluxes by making one side welds in 1 inch and 1 1/4 inch plate.

FULFILLMENT OF QUARTERLY GOALS:

Both major goals have been achieved. Weld performance of an experimental flux identified as 977-14A appears comparable to a commercially established foreign one side welding flux. The foreign flux is identified in this report as flux F-1.

One side welds have been made with flux F-1 in l" and 1 1/2" plate using two AC multipowered electrodes on a flux copper backing system. In conjunction with this, welds have also been made with the experimental flux 977-14A in 1 and 1 l/2" thick plate. Both the top and bottom sides of the welds arc similar in appearance to those obtained with flux F-1. Macro cross-sections of the welds are also similar.

The foreign one side welding flux F-1 has been extensively examined and analyzed by wet chemistry, x-ray fluorescence, x-ray diffraction, and the electron scanning microscope. Results of these examinations are also discussed in this report.

ONE SIDE WELDING FLUXES:

As outlined in the original proposal, four flux systems were considered for investigation in developing a one side welding flux. These systems were as follows:

1. Magnesium Silicate Type
2. Manganese Silicate Type
3. Alumina Silicate Type
4. Calcium Silicate Type

During the first phase of development, over 200 different formulations were prepared which eacompass the four flux systems. The fluxes were initially screened on the basis of weld performance by making single wire bead on plate deposits.

Besides the normal mineral constituents in the fluxes, each formulation contained iron powder in an amount approximately 45% of the total weight. This level of iron powder was selected on the basis of the nominal amount found in an established foreign made one side welding flux through extensive analytical research. The main function of the mineral constituents is to provide atmospheric protection to the deposit during welding. A proper balance and selection of these minerals are, however, necessary in order to achieve a stable welding condition at the high currents required for heavy plate welding. The iron powder in the flux supplements the welding wire by adding filler metal to the deposit. Without this addition extremely high and difficult to handle current levels, would he required. The iron powder is also largely instrumental for the successful formation of the bottom side of the weld.

Of the four flux systems evaluated, the high magnesium oxide or magnesium silicate types have given the most favorable results so far. Flux 977-14A which is principally discussed in this report is of this type. Most of the fluxes that were prepared were centered around this composition with the object of obtaining a material that would have at least equal welding characteristics to flux F-1. These characteristics are 1) high AC amperage capabilities with wide wire spacings on multiwires, 2) good bead appearance both top and bottom, 3) easy slag removal. The chemical composition of flux 977-14A is given in Table I. The mineral components used in the flux are standard commercially available materials which are used in the manufacture of welding electrode coatings and submerged arc fluxes. The iron powder is a sponge iron type which is commonly used in the production of iron powder welding electrodes. A combined source of manganese and silicon alloy was used for the deoxidizers.

The foreign flux F-1 has been extensively analyzed to determine its elemental and compositional make-up. Three complete chemical analyses were obtained on samples received from different sources. Wet chemistry, atomic absorption and x-ray fluorescence techniques were used to determine the elemental constituents. The nominal analysis of flux F-1 is given in Table II. X-ray diffraction methods were used to identify the compounds. Extraction and magnetic separation methods were used to separate the oxide constituents from the metallics so that clearer and more definitive measurements could be accomplished. Tine x-ray patterns showed that the major constituents were magnesium oxide, calcium carbonate, aluminum dioxide, silicon dioxide, calcium fluoride and iron.

Verification of the flux components in flux F-1 was also achieved by using an electron scanning microscope in conjunction with an energy dispersion x-ray analyzer which gives qualitative analysis.

A number of photographs obtained with the electron scanning microscope are shown in Figures 1 to 4, Figure 1 (top) shows an array of flux particles in the as-received condition at 80 magnifications. Each flux particle. consists of many smaller constituents which are the individual flux components which are bonded together. A flux particle from the center of this array is shown in bottom photograph of Figure 1. Identification of the individual constituents of this particle is shown in Figure 2. Calcium carbonate and silicon dioxide are angular in shape which is to be expected since these materials are typically crystalline in nature. The iron particles are spheroidal in appearance. Figure 3 (top) shows an array of iron particles which were magnetically separated from the flux constituents. The particles still have a coating and adhesion of the fluxing constituents. Portions of the coating were identified as sodium oxide and silica which is the sodium silicate binder. The roundness of the iron particles suggests that the iron powder in the flux was produced by some shotting technique. Magnesium oxide and aluminum oxide were also identified as individual constituents. The particles of these were very fine and quite thoroughly dispersed because high magnifications (1.5K) were required to resolve them.

A very significant particle is shown in Figure 4. This particle has been identified as ferromanganese. This definitely establishes that the manganese in the flux is primarily in the form of a metal rather than an oxide. As a metallic, manganese will have a more drastic influence on the weld metal properties. This information will be incorporated in revising the formula of flux 977-14A during the next quarter.

Of the remaining flux systems evaluated, it appears that no further experimentation will be conducted on the manganese and aluminum silicate type fluxes. Although a number of formulations of these types performed satisfactorily under single wire welding conditions, the bead appearance and overall operability were considerably poorer than attained with flux 977-14A and flux F-1. Both of these flux systems are also less conducive towards achieving as high a level of notch toughness as the magnesium and calcium silicate types.

Experimentation, however, will still continue on the calcium silicate type. Several flux formulations of this type which contain zirconium oxide give favorable bead on plate deposits under multiwire conditions.

WELD TEST RESULTS:

One side welds have been made in 1 inch and 1 1/2 inch thick plate following the welding conditions and joint designs which are described in published literature for the flux copper backing method. The welding data for these welds is Listed in Table III. The two wire Scott System was used in all tests.

Grade A515 steel was used throughout because of the unavailability of AM Grade steels. For the remainder of the program ABS Grade steels will he used. The length of all welds was four feet and the weld edges were prepared by machining.

Figure 5 shows a four feet long weld made in 1 inch thick plate using the foreign flux F-1. The weld edges on both the top and bottom (back) side of the weld are reasonably straight and wet into the base plate. The surface of the plate material had a rather heavy layer of mill scale which impaired bead wetting somewhat. Removal of mill scale adjacent to the weld joint or a thinner layer of mill scale would improve edge wetting of the bead but no attempt to remove the mill scale on any of the plates was attempted.

Figure 6 shows a continuous weld made through two different fluxes in 1 inch thick plate. Flux F-1 was used on the first half of the weld and the experimental flux 977-14A was used on the second half. Welding conditions were the same across the length of the weld.

Operability and voltage amperage meter traces appeared comparable. Actually, the experimental flux 977-14A operated with less arc noise than flux F-1. A flame existed around the electrodes of both fluxes during welding. The flame is due to the ignition of small amounts of flammable gases which are generated from the ionization of $CaCo_3$ and chemically combined H_2O in the fluxes.

Visual appearance of the top and bottom section of the weld made with flux 977-14A was at least comparable to that made with flux F-1. Slag peeling from the top of the weld with both fluxes was good. Slag peeling from the bottom of the weld was easier with flux 977-14A as compared to flux F-1. With flux 977-14A most of the fused slag remained in a layer on the copper bar. Sections of the fused slag are shown on the plate in Figure 6. A considerable amount of fused slag remained entrapped along the edges of the bottom of the weld with flux F-1.

Although the chemical composition of both these fluxes are similar as shown in Table I and II, small differences in the chemical composition can drastically affect the welding characteristics such as bead shapes, flux removal, penetration etc. Tine color of flux 977-14A is light gray whereas flux F-1 is light brown. This color difference is insignificant hut it does indicate a difference in chemical composition. The fused portion of.

both slags which was adjacent to the welds was similar in appearance and color.

Cross-sections and small sections of the top and bottom of the 1 inch thick weld which were made with both fluxes are shown in Figures 7 to 10. Full thickness penetration was achieved with both fluxes. The macro cross-sections are similar in appearance. A double bead effect was noticeable on both cross-sections, This apparently results from the partial solidification of molten metal from the first electrode before metal from the second electrode is applied.

A weld made in 1 1/2 inch thick plate with both fluxes is shown in Figure 11. Operability and performance of the fluxes were similar to the 1 inch thick welds. Cross-sections and small sections of the weld are shown in Figures 12 to 15. Weld penetration was complete with both fluxes.

An improvement in bead shape especially to widen out the center of the nugget is desirable to resist cracking tendencies under high restraint. The use of more than two electrodes which will be investigated during the remainder of this program should provide some improvement in bead shape.

CHEMICAL COMPOSITION

Flux 977-14A

Component	PerCent
MgO	16.81
SiO_2	13.84
$CaCO_3$	8.26
CaO	1.12
Al_2O_3	2.90
CaF_2	3.10
Mn	4.54
Si	2.16
Na_2O	2.92
K_2O	0.62
Fe	43.72

Table I

CHEMICAL COMPOSITION

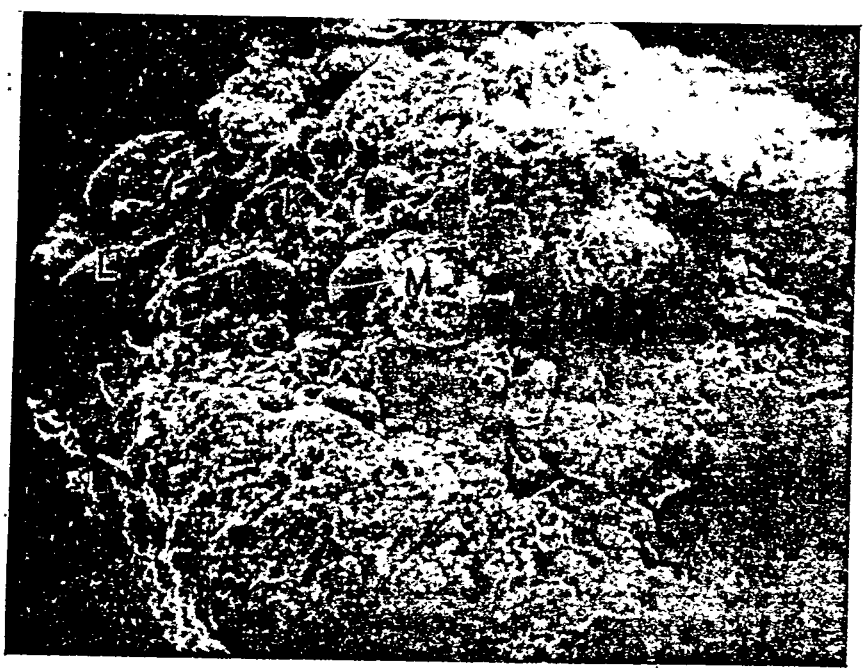
Flux F-1

Component	PerCent
MgO	15.2
SiO_2	15.1
$CaCO_3$	8.6
CaO	2.1
Al_2O_3	3.8
CaF_2	3.3
MnO *	3.3
Na_2O	1.6
K_2O	0.13
S	0.01
Cr_2O_3	<0.1
MoO_3	<0.1
ZrO_2	<0.1
NiO	<0.1
Fe	46.8

* MnO is principally Mn.

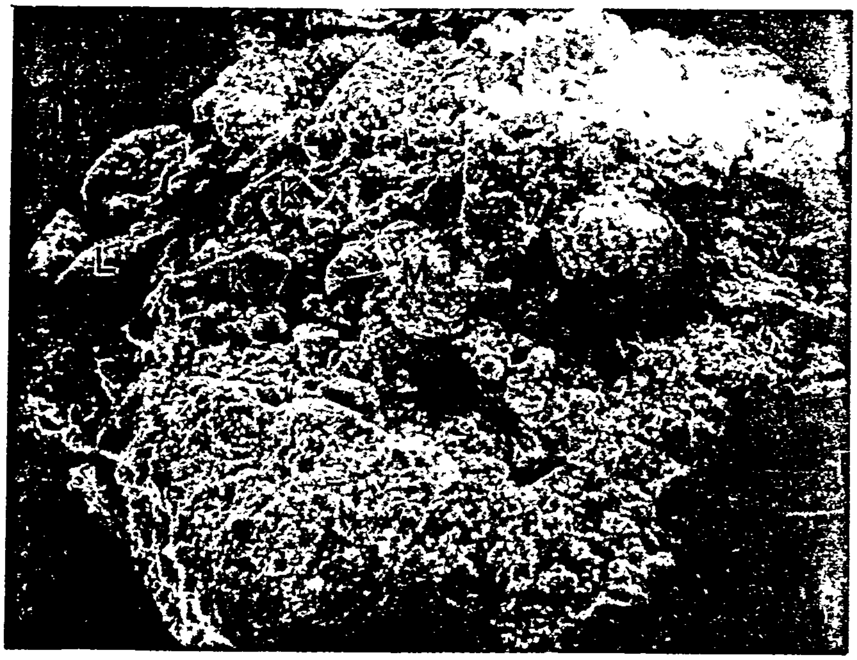
Table II

Flux F-1 particles at 80 Magnification



Center particle A from above at 400 Magnification

Fig. 1



Particle A at 400 Magnification

Subparticle M identified as Fe
Subparticle L identified as $Ca\ C0_3$
Subparticle J identified as Fe
Subparticles K identified as $Si0_2$

Fig. 2

Magnetically separated particles
Round particles are Fe
Magnification 80

Fe particle with attached oxides
Magnification 155

Fig. 3

Particle H identified as Fe Mn
Magnification 80

Fig. 4

SUBMERGED ARC ONE SIDE WELDING CONDITIONS

Weld Number	Figure Number	Plate Thickness	Joint Preparation	Lead Wire Amperes AC	Lead Wire Volts AC	Trail Wire Amperes AC	Trail Wire Volts AC	Travel Speed ipm	Materials
976-1	5	1"-A515 Steel	50° Inc. angle 21/32" deep 3/32" Nose 60° Inc. angle 1/4" deep	1225	37	980	48	17	2-Linde 3/16"-43 Wires F-1 Flux
976-17	6	1"-A515 Steel	50° Inc. angle 21/32" deep 3/32" Nose 60° Inc. angle 1/4" deep	1225	37	980	48	17	2-Linde 3/16"-43 Wires F-1 Flux
976-17A	6	1"-A515 Steel	50° Inc. angle 21/32" deep 3/32" Nose 60° Inc. angle 1/4" deep	1225	37	980	48	17	2-Linde 3/16"-43 Wires 977-14A Flux
976-171	11	1 1/2"-A515 Steel	40° Inc. angle 1 1/8" deep 3/16" Nose 60° Inc. angle 1/4" deep	1550	36	1080	55	14	2-Linde 3/16"-43 Wires F-1 Flux
976-171A	11	1 1/2"-A515 Steel	40° Inc. angle 1 1/8" deep 3/16" Nose 60° Inc. angle 1/4" deep	1550	36	1080	55	14	2-Linde 3/16"-43 Wires 977-14A Flux

TABLE III

WIRE SPACING

Welds 976-1, 976-17, 976-17A (1" A515)

Wires Vertical with 4 1/2" center to center spacing.
Tip to work extension 1 1/2"

Weld 976-171, 976-171A (1 1/2" A515)

Wires Vertical with 5" center to center spacing.
Tip to work extension 1 5/8"

BACKING METHOD

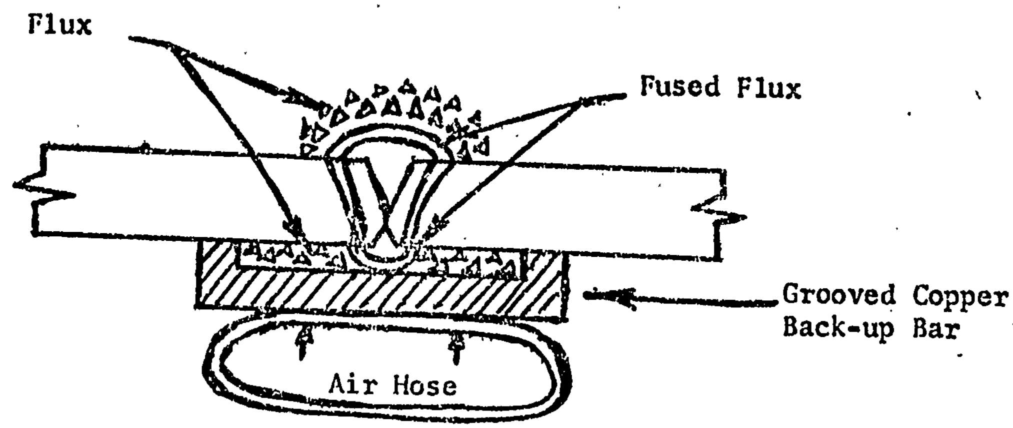
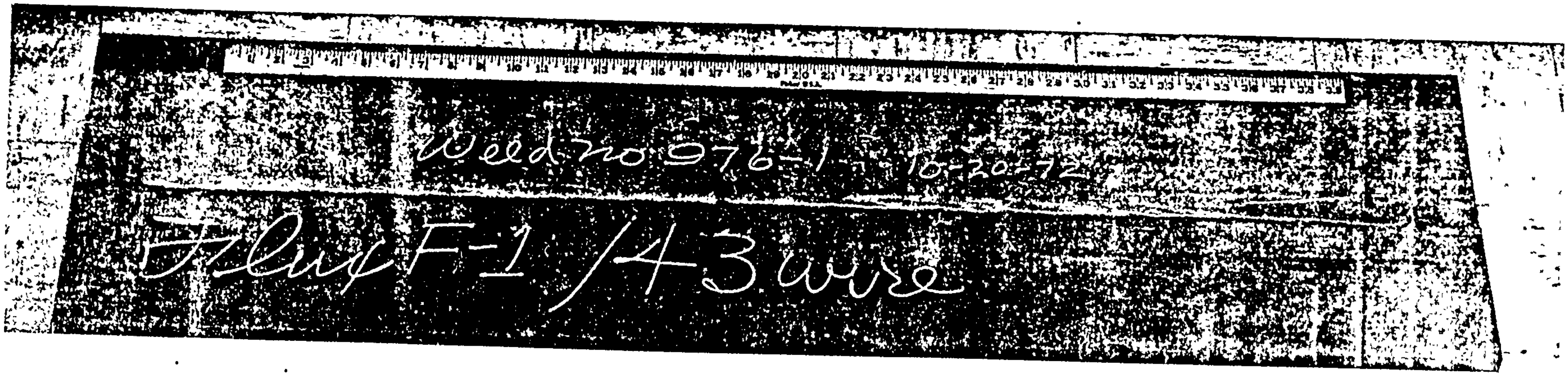


TABLE III
Page 2



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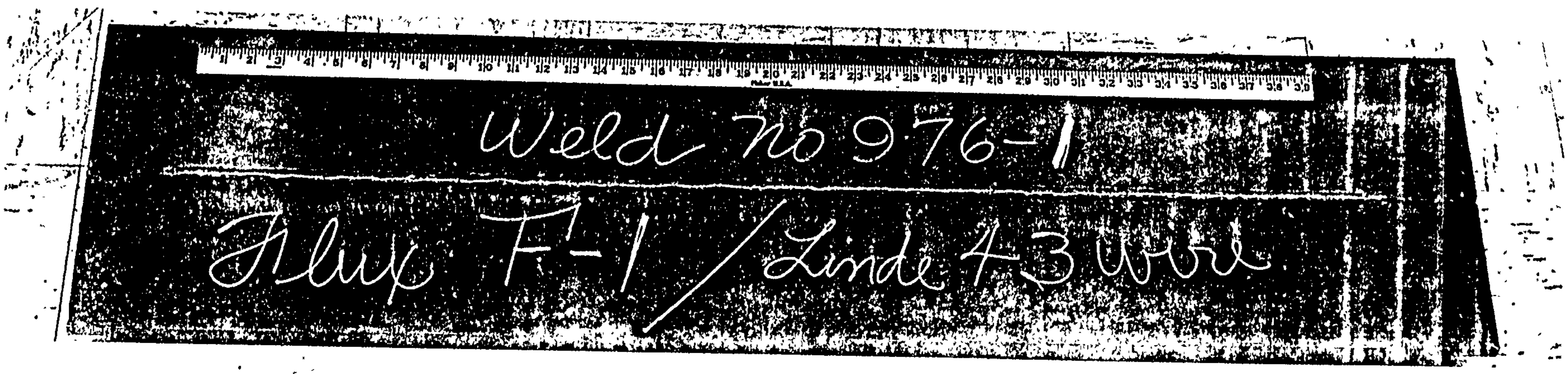

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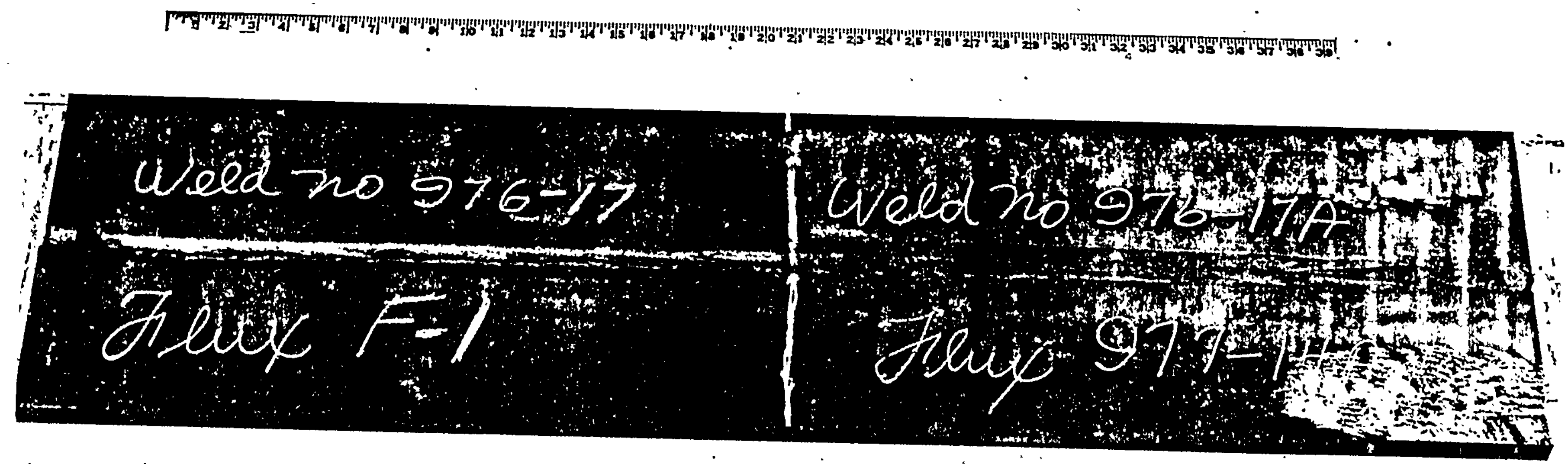
Fig. 5



Top

Back

Fig. 6

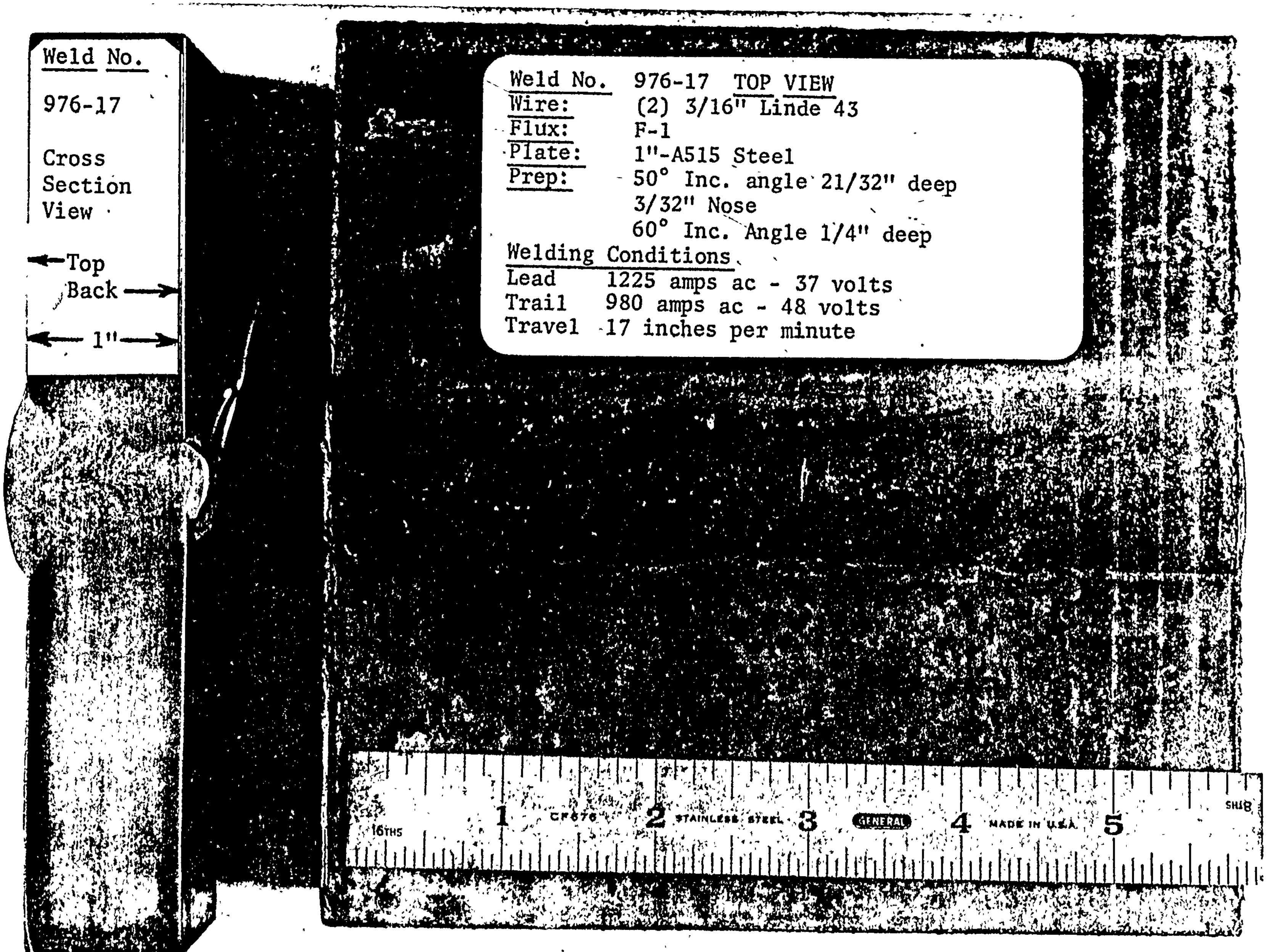
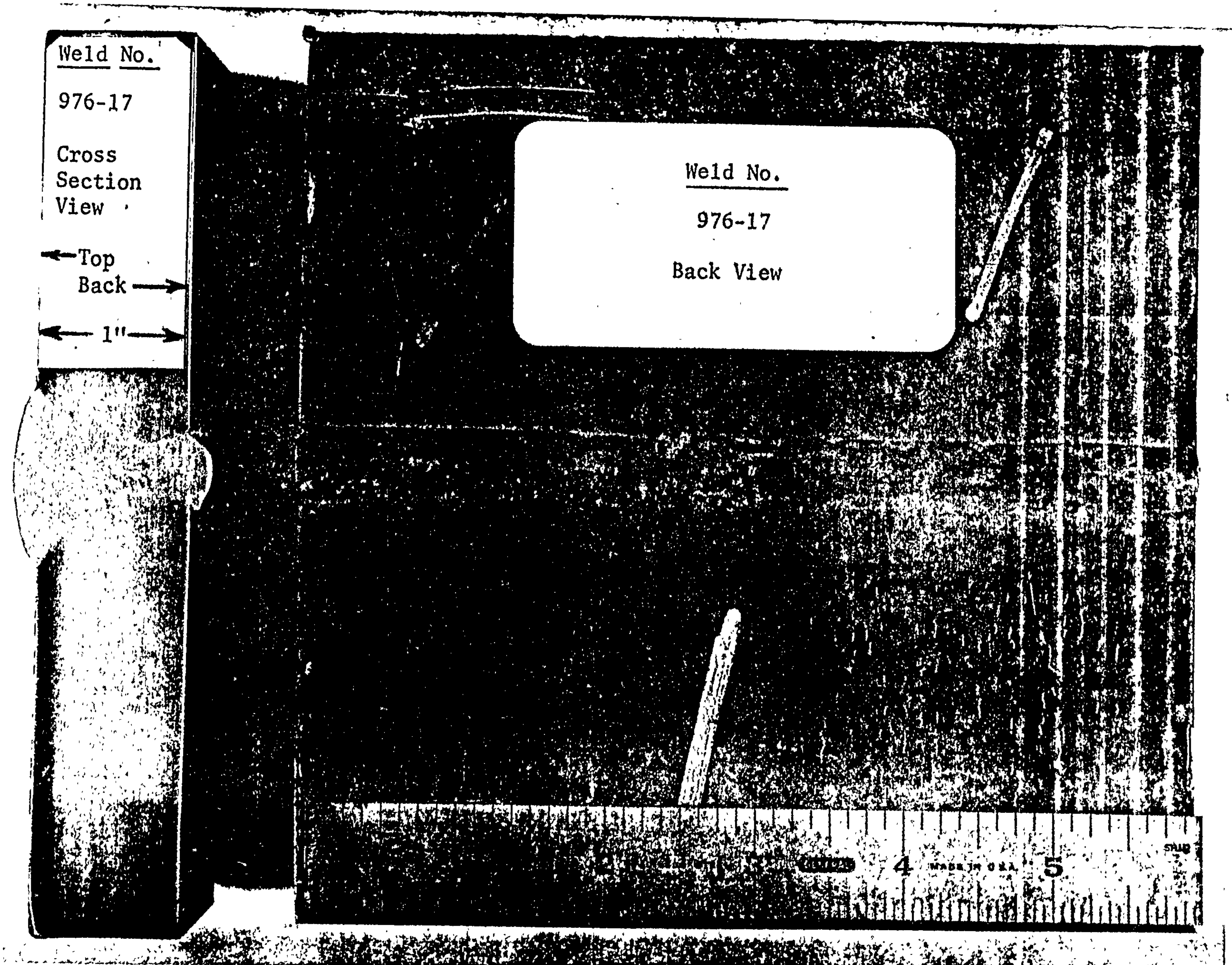

Weld No.
976-17
Cross
Section
View
Top
Back
1"
Weld No. 976-17 TOP VIEW
Wire: (2) 3/16" Linde 43
Flux: F-1
Plate: 1"-A515 Steel
Prep: 50° Inc. angle 21/32" deep
3/32" Nose
60° Inc. Angle 1/4" deep
Welding Conditions
Lead 1225 amps ac - 37 volts
Trail 980 amps ac - 48 volts
Travel 17 inches per minute
16THS
1
2
STAINLESS STEEL
3
GENERAL
4
MADE IN U.S.A.
5

Fig. 7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976-17
Cross Section View
Top
Back
1"
Weld No.
976-17
Back View
4
5

Fig. 8

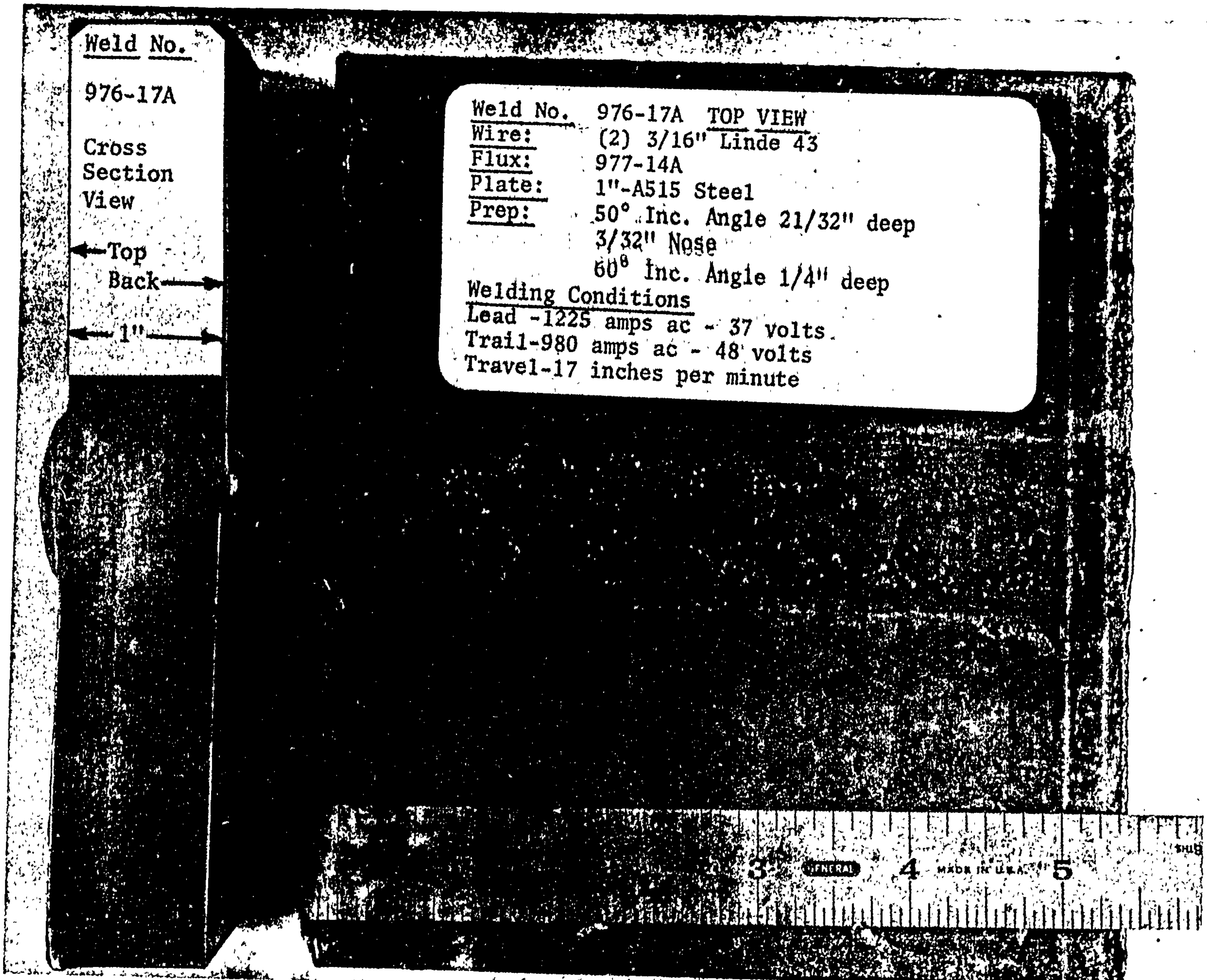
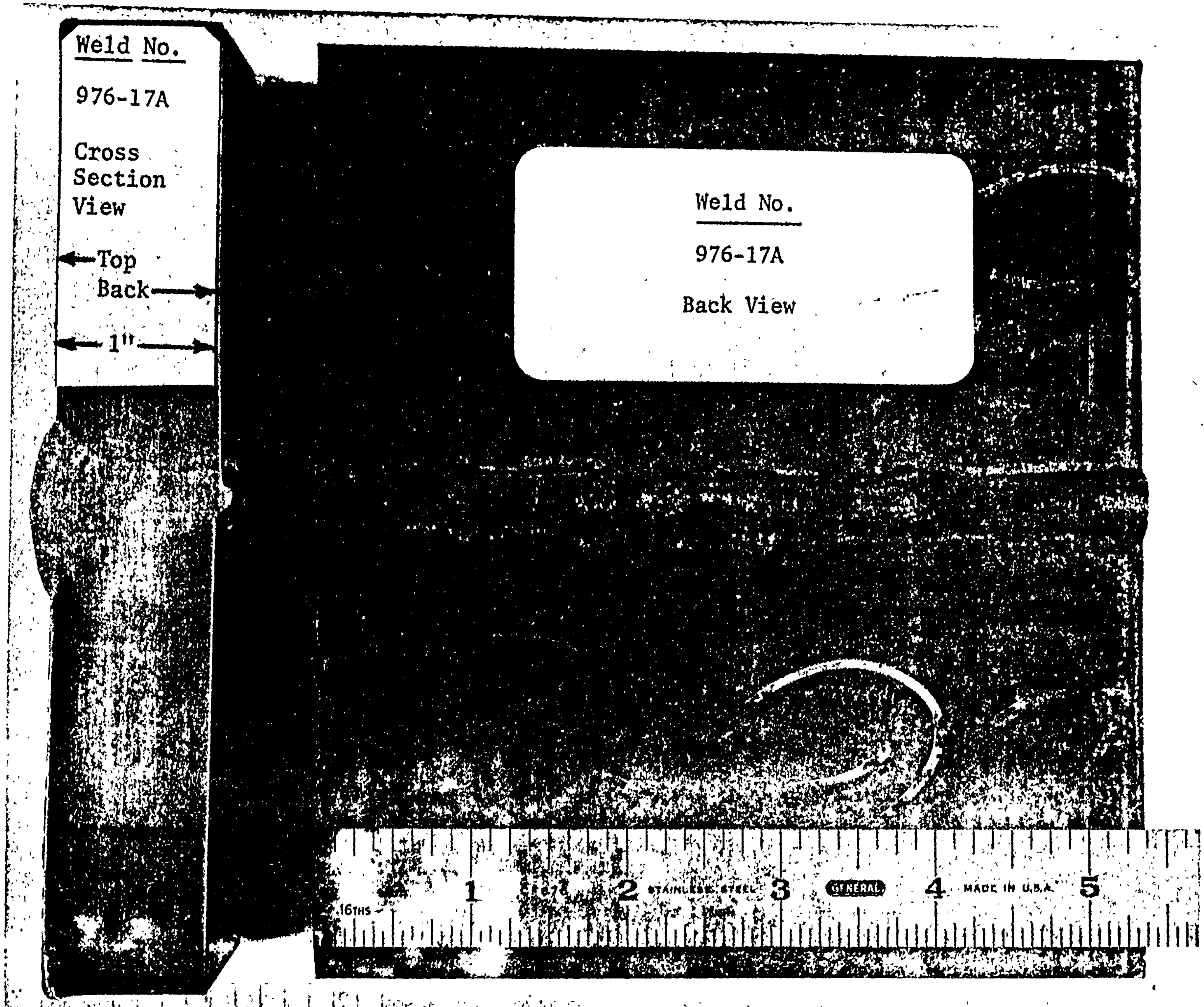

Weld No.
976-17A
Cross Section View
Top
Back
1"
Weld No. 976-17A TOP VIEW
Wire: (2) 3/16" Linde 43
Flux: 977-14A
Plate: 1"-A515 Steel
Prep: 50° Inc. Angle 21/32" deep
3/32" Nose
60° Inc. Angle 1/4" deep
Welding Conditions
Lead -1225 amps ac - 37 volts
Trail-980 amps ac - 48 volts
Travel-17 inches per minute
3
GENERAL
4
MADE IN U.S.A.
5

Fig. 9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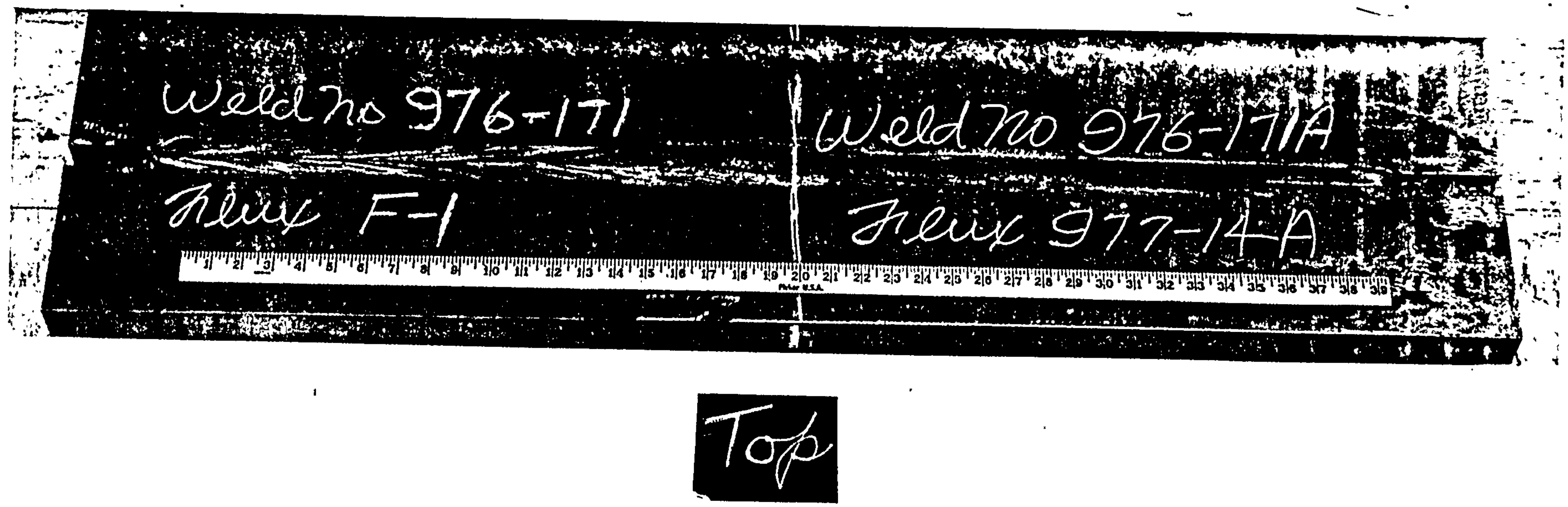
976-17A
Cross Section View
Top
Back
1"
Weld No.
976-17A
Back View
16THS
1
2
STAINLESS STEEL
3
GENERAL
4
MADE IN U.S.A.
5

Fig. 10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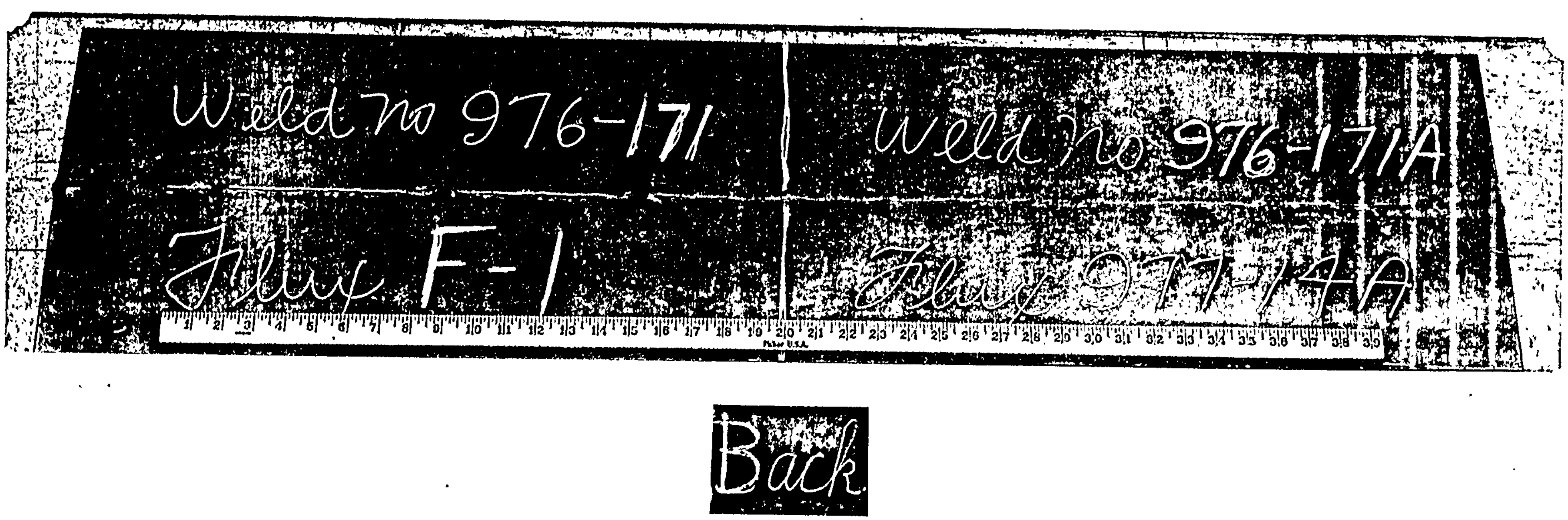
Weld No 976-171A
Flux F-1
Flux 977-14-A
Top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Weld No 976-171A
Flux F-1
Flux 977-14-A
Back

Fig. 11

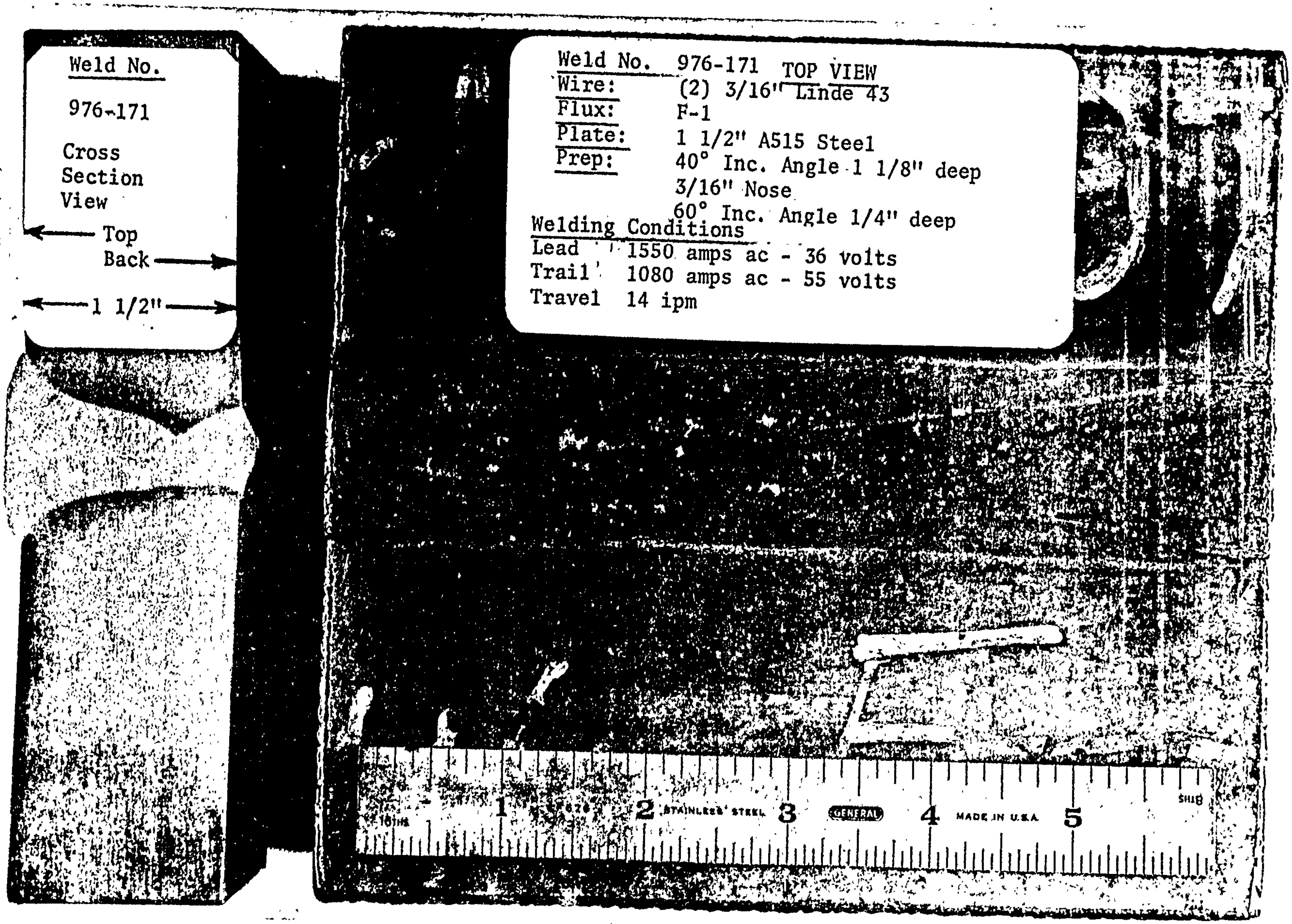

Weld No.
976-171
Cross
Section
View
Top
Back
1 1/2"
Weld No. 976-171 TOP VIEW
Wire: (2) 3/16" Linde 43
Flux: F-1
Plate: 1 1/2" A515 Steel
Prep: 40° Inc. Angle 1 1/8" deep
3/16" Nose
60° Inc. Angle 1/4" deep
Welding Conditions
Lead 1550 amps ac - 36 volts
Trail 1080 amps ac - 55 volts
Travel 14 ipm
1
2
STAINLESS STEEL
3
GENERAL
4
MADE IN U.S.A.
5

Fig. 12

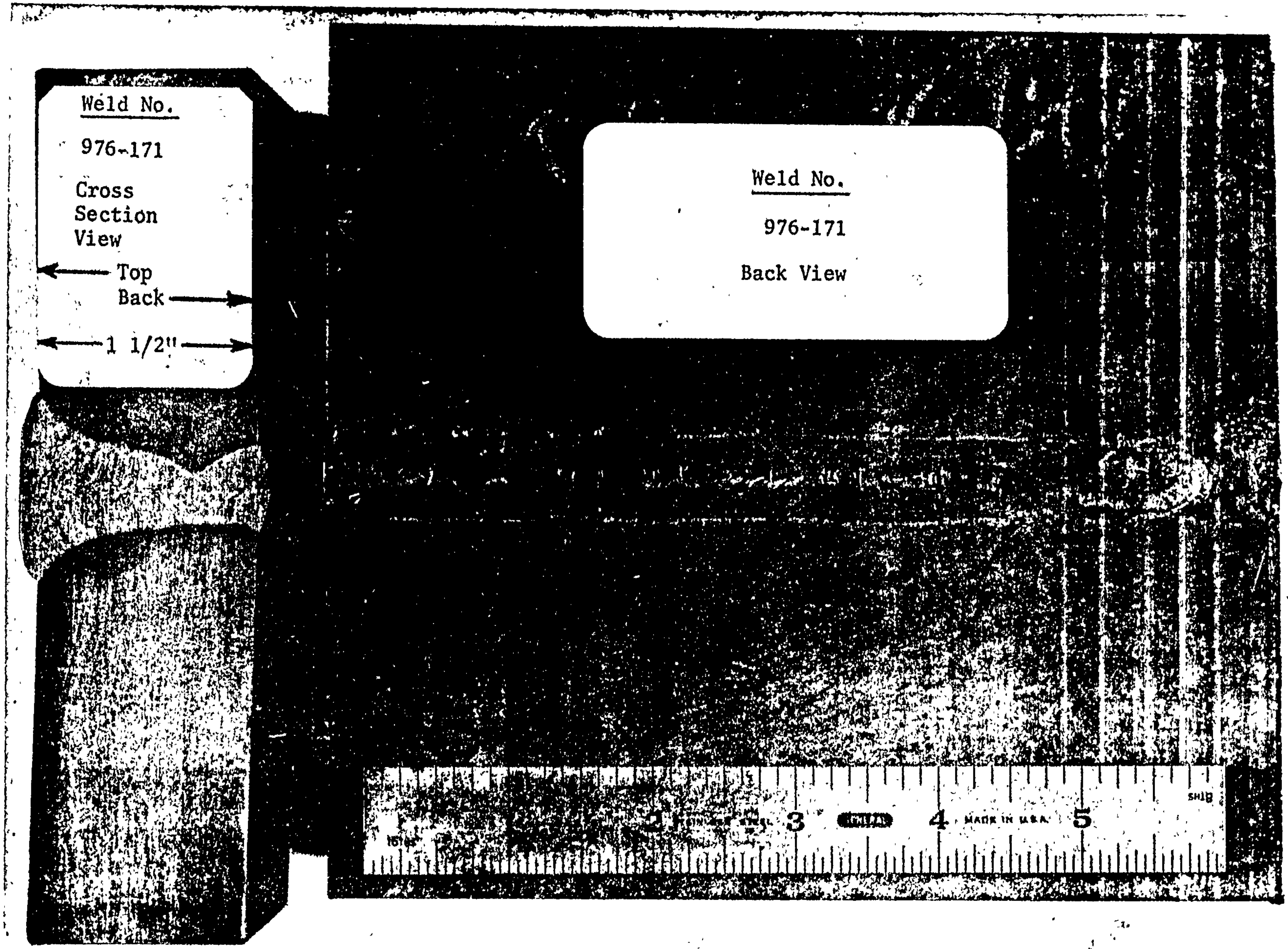

Weld No.
976-171
Cross Section View
Top
Back
1 1/2"
Weld No.
976-171
Back View
2
3
4
MADE IN U.S.A.
5

Fig. 13

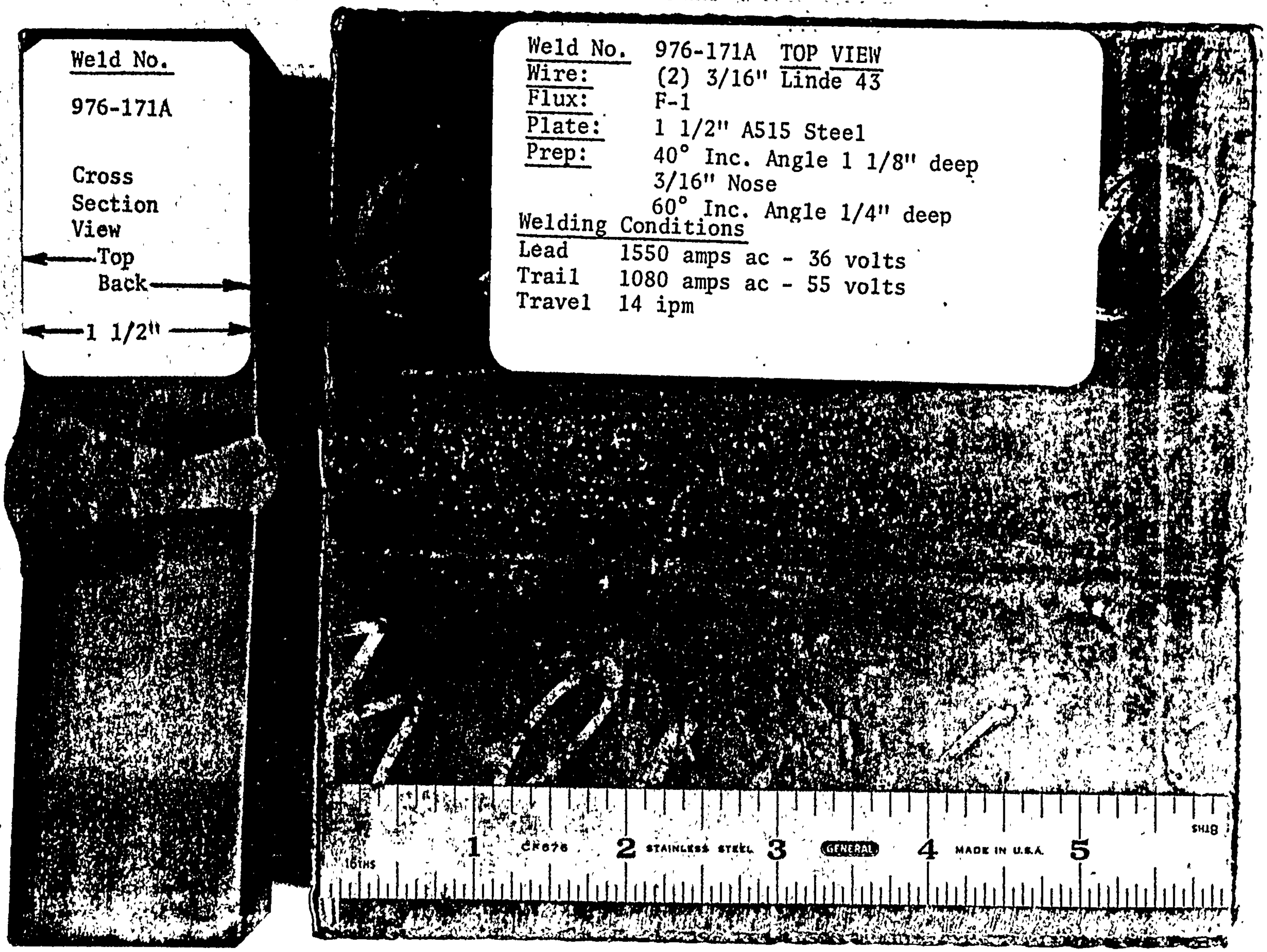

Weld No.
976-171A
Cross
Section
View
Top
Back
1 1/2"
Weld No. 976-171A TOP VIEW
Wire: (2) 3/16" Linde 43
Flux: F-1
Plate: 1 1/2" A515 Steel
Prep: 40° Inc. Angle 1 1/8" deep
3/16" Nose
60° Inc. Angle 1/4" deep
Welding Conditions
Lead 1550 amps ac - 36 volts
Trail 1080 amps ac - 55 volts
Travel 14 ipm
1 2 STAINLESS STEEL 3 GENERAL 4 MADE IN U.S.A. 5

Fig. 14

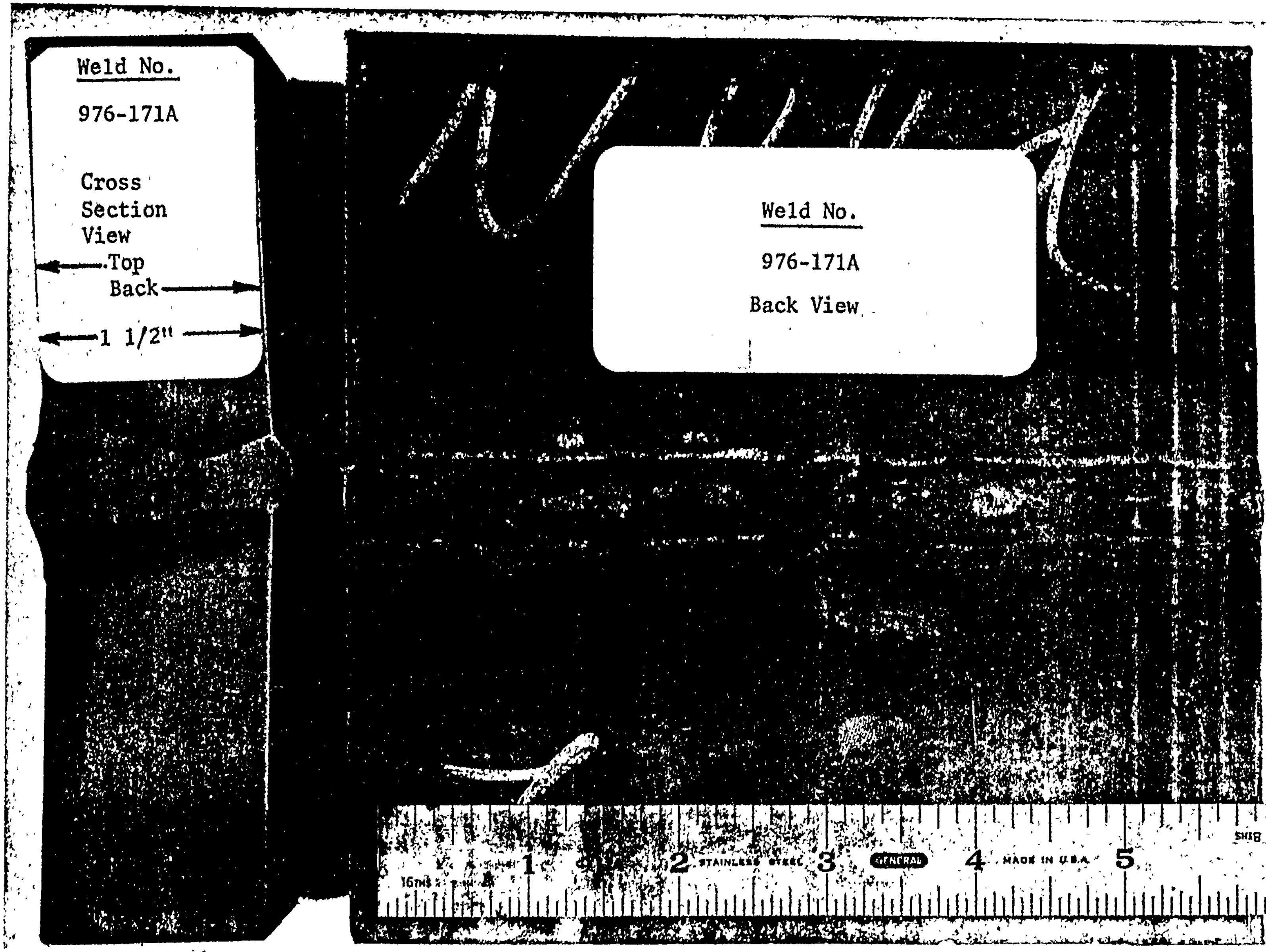

Weld No.
976-171A
Cross Section View
Top
Back
1 1/2"
Weld No.
976-171A
Back View
1 2 STAINLESS STEEL 3 GENERAL 4 MADE IN U.S.A. 5

Fig. 15

Report No. 1

Project SP-1-1 Part 102
Contract No. 1560-721 -1510-S/02.3764-C
One Side Welding Multiple Arc Study

Program Objective

To provide sufficiently high travel speeds for economical one side welding of ship plates a multi-electrode submerged arc system is necessary.

For the production of one side, one pass butt welds in 1 1/2" thick plate, even our presently existing three electrode systems will not be sufficient to achieve the desired 25 to 30 ipm travel speeds.

The goal of the program is to develop a four electrode welding system capable of depositing metal at the rate of 120 to 150 lbs/hr. A four electrode system operating at from 1,000 to 1,500 amps per electrode will provide the required deposition rate and should attain the welding speeds desired.

FIRST QUARTER GOALS:

The goals of the first quarter of this program are:

1. Make a theoretical study of several power connections analyzing several promising power phasing connections for theoretically best performance.

By developing arc deflection equations for each arc and each system selected the theoretically best systems can be tested further.

2. Assemble existing components to convert an existing three wire AC-AC-AC system into a four wire all AC welding system.

FULFILLMENT OF QUARTERLY GOALS:

Both major goals have been achieved. The equipment required for a four electrode AC system has been assembled and installed. The major equipment components consist of (4) Linde UEC-6 controls (4) Linde UEH-1 and UEH-2 wirefeeders (4) AC constant current power sources and appropriate slides, mounting brackets, nozzles, all mounted on a Linde OM-48 travel carriage.

A theoretical arc deflection analysis has been completed with the aid of our Tarrytown Computer Services Group. Of the four power phasing systems analyzed and the sixteen separate variations evaluated, two appear to offer the best chance of success, The two systems selected optimize the arc deflection pattern, total ground current, and our practical working knowledge of high current multipower systems. They employ a 90 degree Scott and 60 + 120 degree electrode current phase displacements.

TECHNICAL DETAILS OF THEORETICAL ARC. DEFECTION ANALYSIS:

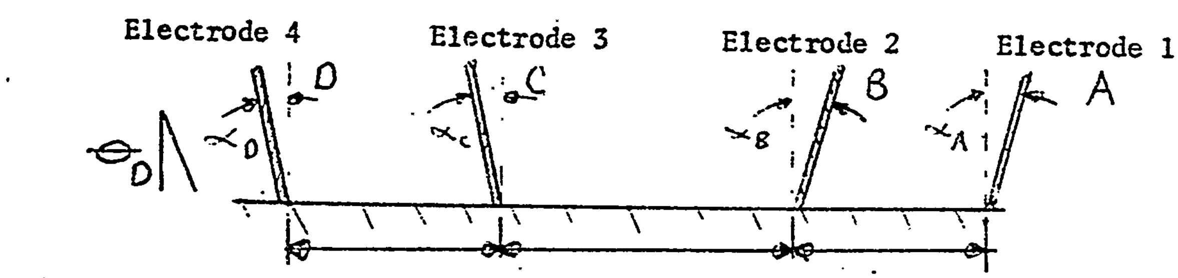
It had been shown in the development of Three Wire Submerged Arc welding of Line Pipe (copy attached) that the deflection pattern of especially the Traii Arc was of major importance in controlling final weld shape. Using the theoretical method of predicting arc deflection developed in that work a similar model was developed for a four electrode system. With this model and subsequent analysis it is possible to select from the almost infinite possible combinations the better systems of connecting the 4 single phase AC transformers to the 3 phase 440 Volt power line.

Considering all variables the better electrode spacings, wire angles, ground currents, as well as power phasings can also be evaluated.

FOUR ELECTRODE MODEL:

The four electrode model was developed using the method followed in the attached three wire reference.

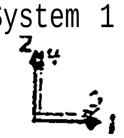
The arc deflection equation for the fourth or trail electrode is presented below to indicate the important variables considered. Equations for the first, second and third electrodes were developed in a similar manner.



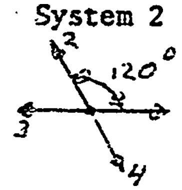
$$\text{Arc Deflection at Elec. 4} = \frac{\alpha_D}{2} + \arctan C_o \frac{L^2}{I_n}\left(\frac{I_C}{D_1^2} + \frac{I_B}{(D_1+D_2)^2} + \frac{I_A}{(D_1+D_2 \ldots}\right.$$

After consideration **of** the possible power phasing systems it was decided to theoretically investigate four systems. These are shown vectorially below:

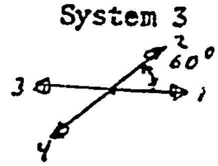
System 1



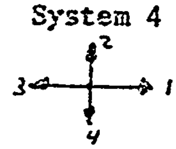
System 2



System 3



System 4



,Systems 1 and 4 are essentially a double Scott system while systems 2 and 3 utilize 120 and 60 degrees phase shifts between adjacent electrodes.

These power phasing systems with selected currents and several electrode angle and spacing differences were outlined and are shown in Table I. As shown, 16 separate systems were analyzed.

Two of the power phasing systems employ pairs of Scott connected transformers because of the known superior performance of this connection. The other two phasing systems use combinations of 60 and 120 degrees electrode current phase displacements far ease of transformer connections. This also eliminates the necessity of lowering the current capacity of the lead transformer as is required in the Scott connected system.

Specific phase displacement angles were selected for three of the systems to provide low ground currents. This eliminates the mechanical and electrical problems created when high ground currents are employed.

The arc deflection equations developed were used to determine each arc deflection in each of the 16 system selected. The total ground currents were also determined. The data points generated by a computer program were then plotted by machine and a separate arc deflection graph was generated for each system analyzed.

ARC DEFLECTION RESULTS:

Within each of the four power phasing systems-there were four different electrode spacings evaluated. As expected, the largest deflections are created at close electrode spacings. At electrode spacings of six inches, very little deflection is created by adjacent electrodes , initial electrode inclination angle being of major importance. A comparison of the arc deflection changes caused by differing electrode spacings is presented for power system 4 in attached arc deflection graphs 4A, 4B, 4C, 4D.

System 4A shows 2 good deal of movement in the third and fourth electrodes. After both arcs ignite, the deflection is mostly in the forward direction. Before extinguishing deflection is over 10 degrees forward. The first and second electrode move very little. Discounting the ignition and extinguishing regions only two or three degrees of arc movement take place.

As the electrodes are spaced farther apart to three inches in 4B, the arc movement becomes very small. In system 4C, with six inch spacings practically no arc movement occurs between ignition and extinguishing.

In system 4D substantial arc movement occurs because of the close, 1.5 inch, spacing between the electrodes in both the forward and rear pair.

Therefore, only with at least a pair of electrodes closely spaced can advantage be taken of a forward sweeping arc to achieve higher welding speeds.

For a comparison of the 4 power phasing systems, arc deflection graphs for systems 1A, 2A, 3A and 4A are attached. Since the deflection of the trail arc or possibly the last two arcs are of most importance for final weld shapes we can concentrate our attention to these last one or two electrodes. Examining the deflection pattern of electrodes 3 and 4 for each system we see:

1. In all systems electrodes 3 and 4 deflect predominantly forward. Mainly as a result of the initial wire inclination angle.

2. In system 1A and 2A the third and fourth arcs have a backward sweeping motion. This is not a favorable pattern.

3. In systems 3A and 4A both electrodes 3 and 4 sweep in almost a similar pattern from slightly backward to substantially forward. This is a very favorable pattern.

Also in systems 3A and 4A electrodes 1 and 2 have relatively small deflections which should be useful in providing uniform penetration and underside weld.

Another consideration in selecting the power phasing system is ground current developed. The ground currents developed for each of the 4 power phasing system under consideration are listed below:

System 1-3200 Amps (RMS) positive peak at 309.5°
System 2-220 Amps (RMS) positive peak at 306°
System 3-346 Amps (RM$) positive peak at 112°
System 4-289 Amps (RMS)positive peak at 120°

As seen, all but system 1 have very low ground currents which is a major advantage in connecting ground cables, compensating for voltage drops, and preventing unusual end conditions for example.

Considering all factors it appears power phasing-systems 3 and 4 offer the most advantages and have no draw backs. These will then be considered for further testing.

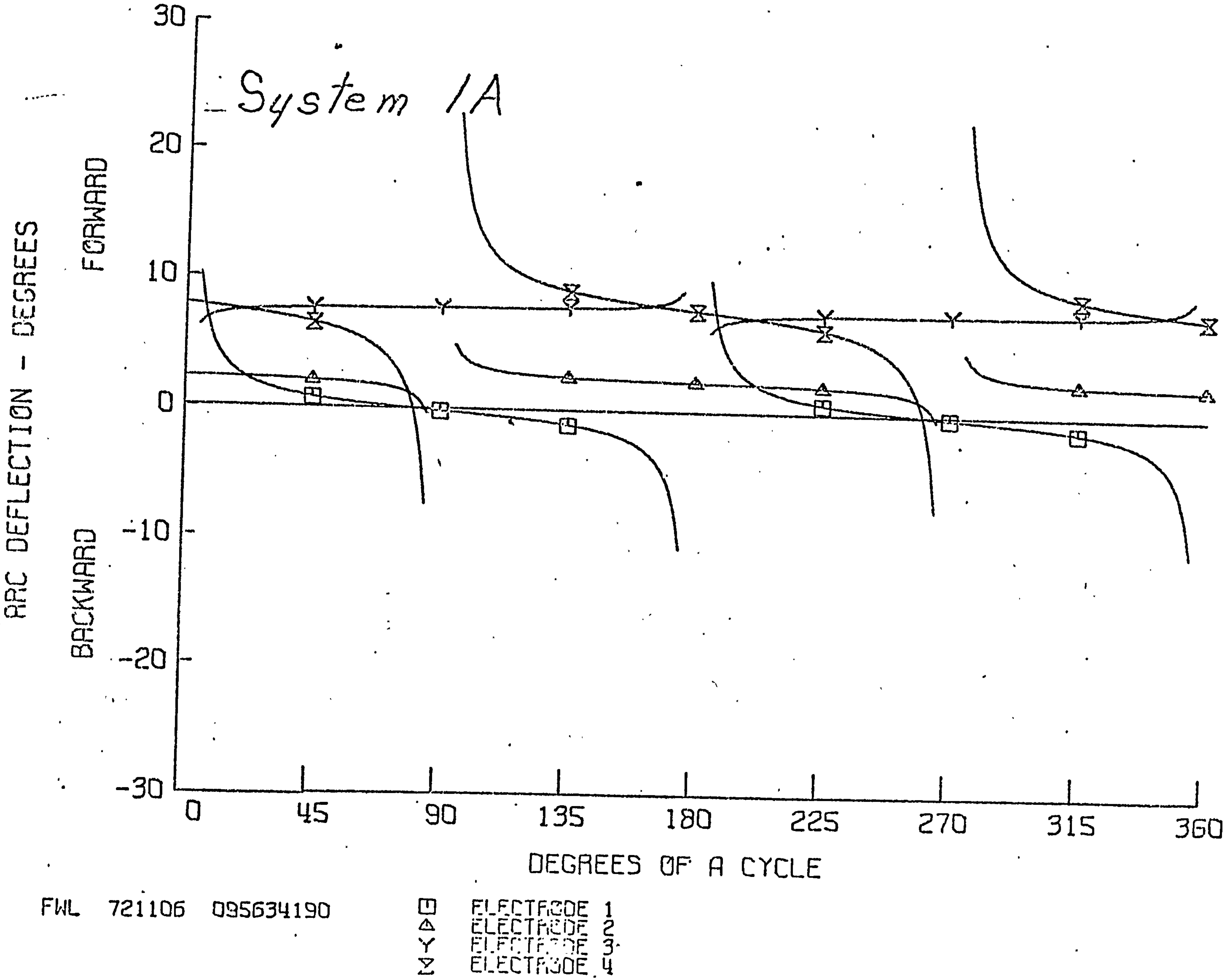
Although electrode spacing is a variable and will be used to optimize parameters the spacing and arc deflections for systems 3D and 4D appear to offer the most advantages. The six inch-spacing between the lead pair and trail pair of electrodes should enable the separation of underbead and top bead formation which is highly desirable. The close spacing of electrodes 1 and 2 will also allow a concentration of arc power to provide the required penetration. The deflection patterns are still quite favorable with little change in deflection noted from systems 3A and 4A.

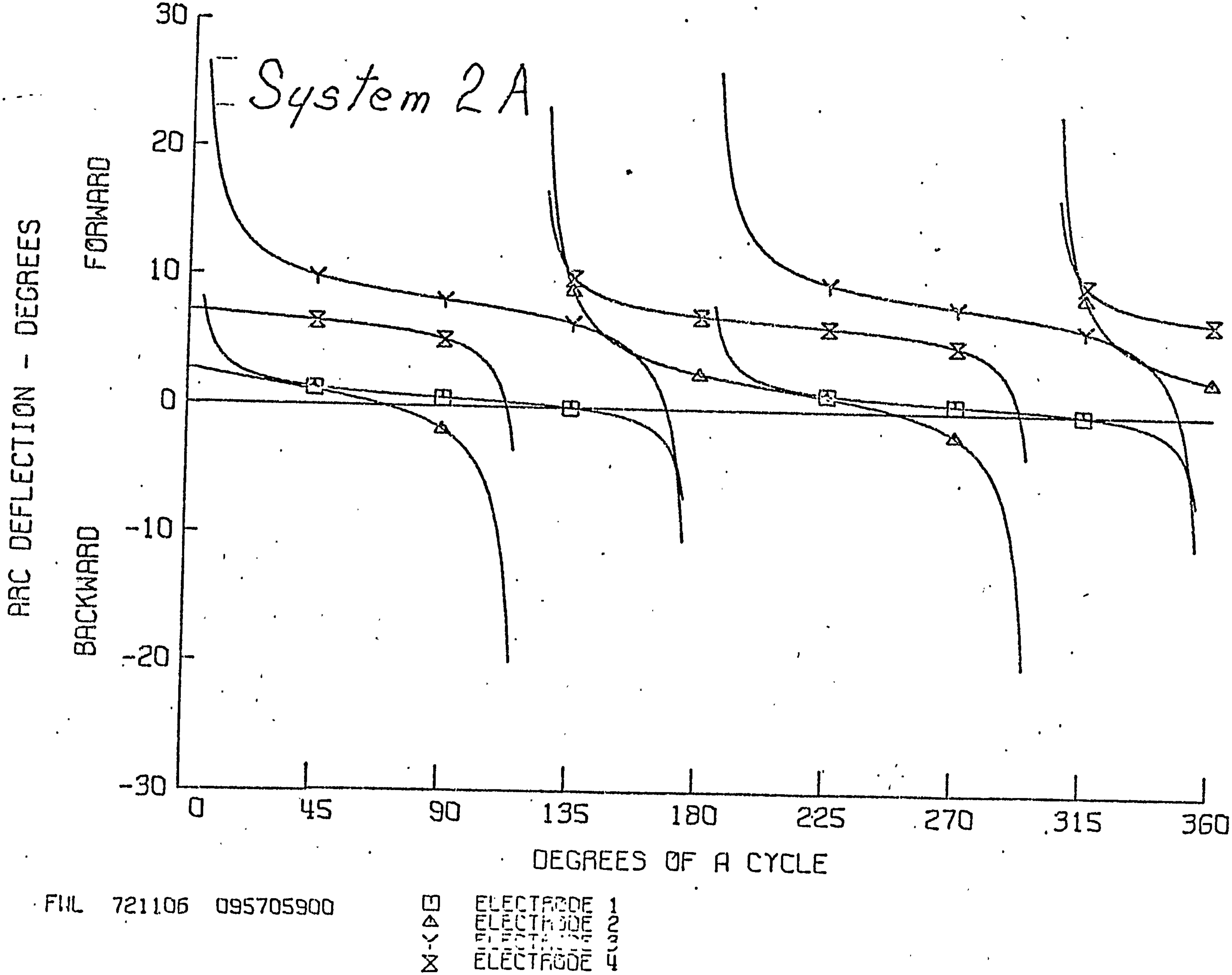
Therefore, systems 3D and 4D appear to have the most promise and will be the first to be evaluated under actual welding conditions.

4 ELECTRODE THEORETICAL ARC DEFLECTION STUDY

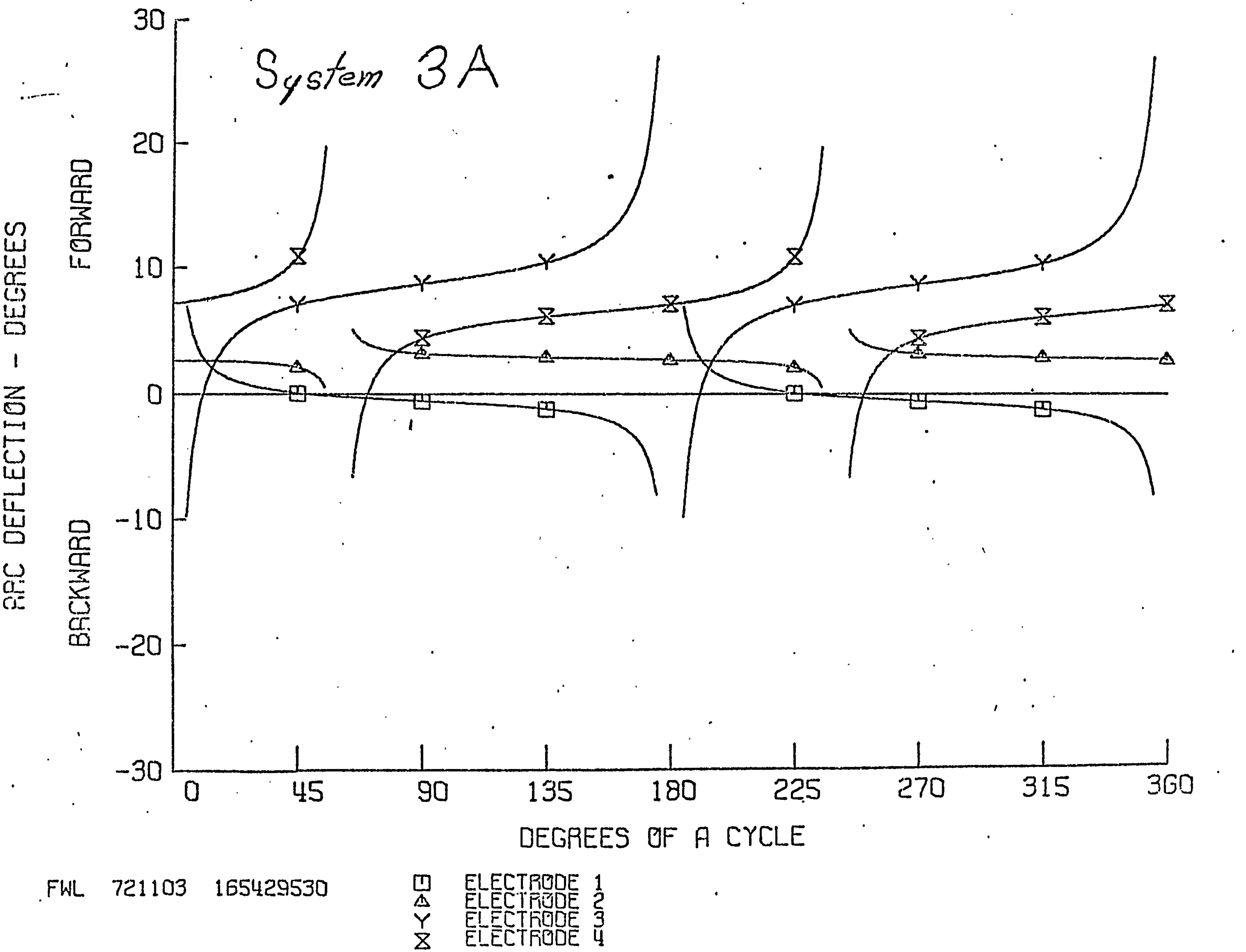
AMPS=Irms $\sqrt{2}$

System	I_A	I_B	I_C	I_D	degrees αA	αB	αC	αD	inches D_1	D_2	D_3
1A	1910(sin θ)	1560(sinθ-90)	1560(sinθ)	1350(sinθ-90)	0	+5	+15	+15	1.5	1.5	1.5
1B	1910(sin θ)	1560(sinθ-90)	1560(sinθ)	1350(sinθ-90)	0	+5	+15	+15	3	3	3
1C	1910(sin θ)	1560(sinθ-90)	1560(sinθ)	1350(sinθ-90)	0	0	+10	+10	6	6	6
1D	1910(sin θ)	1560(sinθ-90)	1560(sinθ)	1350(sinθ-90)	0	+5	+10	+15	1.5	6	1.5
2A	1910(sin θ)	1560(sinθ-120)	1560(sinθ-180)	1350(sinθ-300)	0	+5	+15	+15	1.5	1.5	1.5
2B	1910(sin θ)	1560(sinθ-120)	1560(sinθ-180)	1350(sinθ-300)	0	+5	+15	+15	3	3	3
2C	1910(sin θ)	1560(sinθ-120)	1560(sinθ-180)	1350(sinθ-300)	0	0	+10	+10	6	6	6
2D	1910(sin θ)	1560(sinθ-120)	1560(sinθ-180)	1350(sinθ-300)	0	+5	+10	+15	1.5	6	1.5
3A	1910(sin θ)	1560(sinθ-60)	1560(sinθ-180)	1350(sinθ-240)	0	+5	+15	+15	1.5	1.5	1.5
3B	1910(sin θ)	1560(sinθ-60)	1560(sinθ-180)	1350(sinθ-240)	0	+5	+15	+15	3	3	3
3C	1910(sin θ)	1560(sinθ-60)	1560(sinθ-180)	1350(sinθ-240)	0	0	+10	+10	6	6	6
3D	1910(sin θ)	1560(sinθ-60)	1560(sinθ-180)	1350(sinθ-240)	0	+5	+10	+15	1.5	6	1.5
4A	1910(sin θ)	1560(sinθ-90)	1560(sinθ-180)	1350(sinθ-270)	0	+5	+15	+15	1.5	1.5	1.5
4B	1910(sin θ)	1560(sinθ-90)	1560(sinθ-180)	1350(sinθ-270)	0	+5	+15	+15	3	3	3
4C	1910(sin θ)	1560(sinθ-90)	1560(sinθ-180)	1350(sinθ-270)	0	0	+10	+10	6	6	6
4D	1910(sin θ)	1560(sinθ-90)	1560(sinθ-180)	1350(sinθ-270)	0	+5	+10	+15	1.5	6	1.5

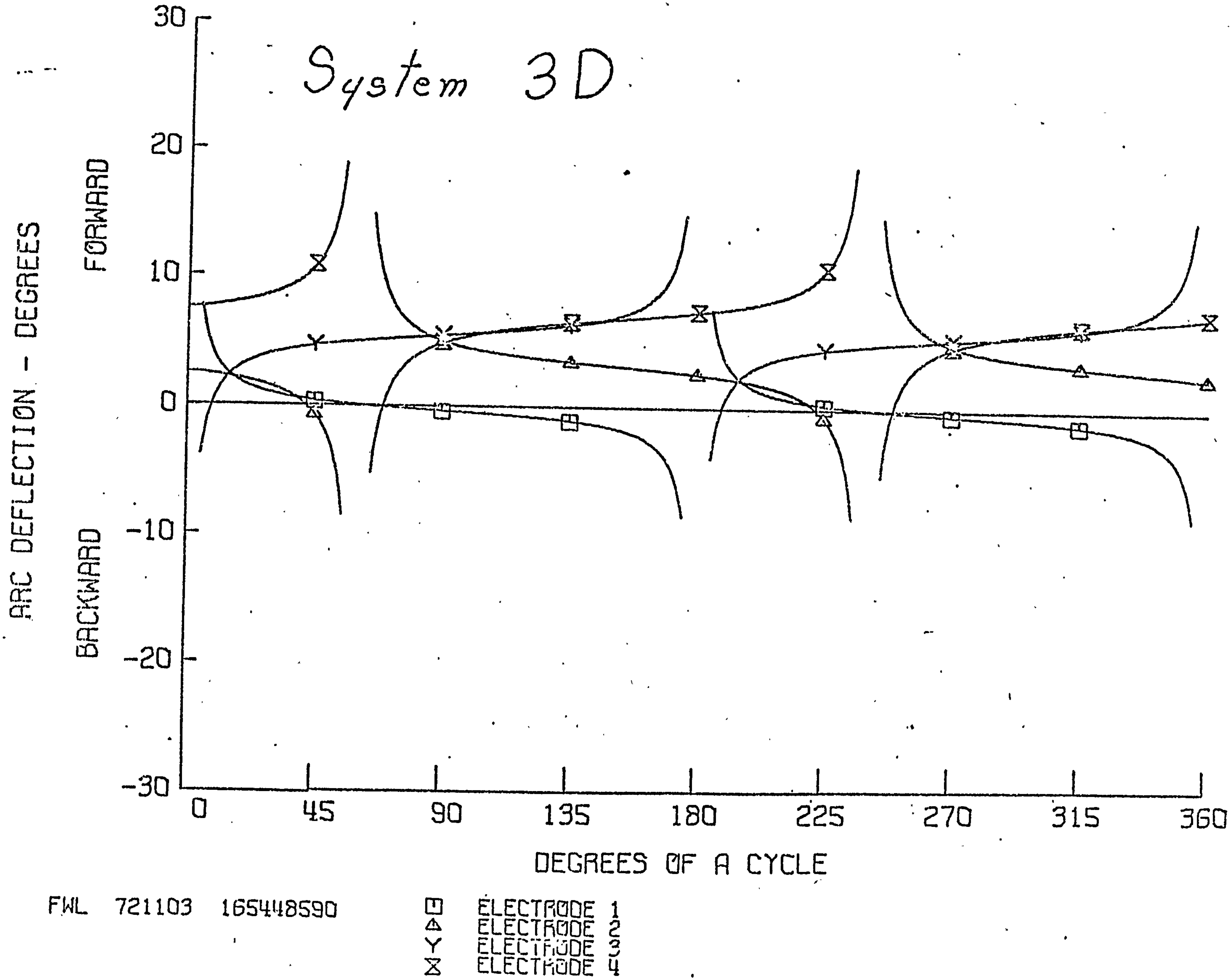

System 1A
ARC DEFLECTION - DEGREES
FORWARD
BACKWARD
30
20
10
0
-10
-20
-30
0
45
90
135
180
225
270
315
360
DEGREES OF A CYCLE
FWL 721106 095634190
ELECTRODE 1
ELECTRODE 2
ELECTRODE 3
ELECTRODE 4

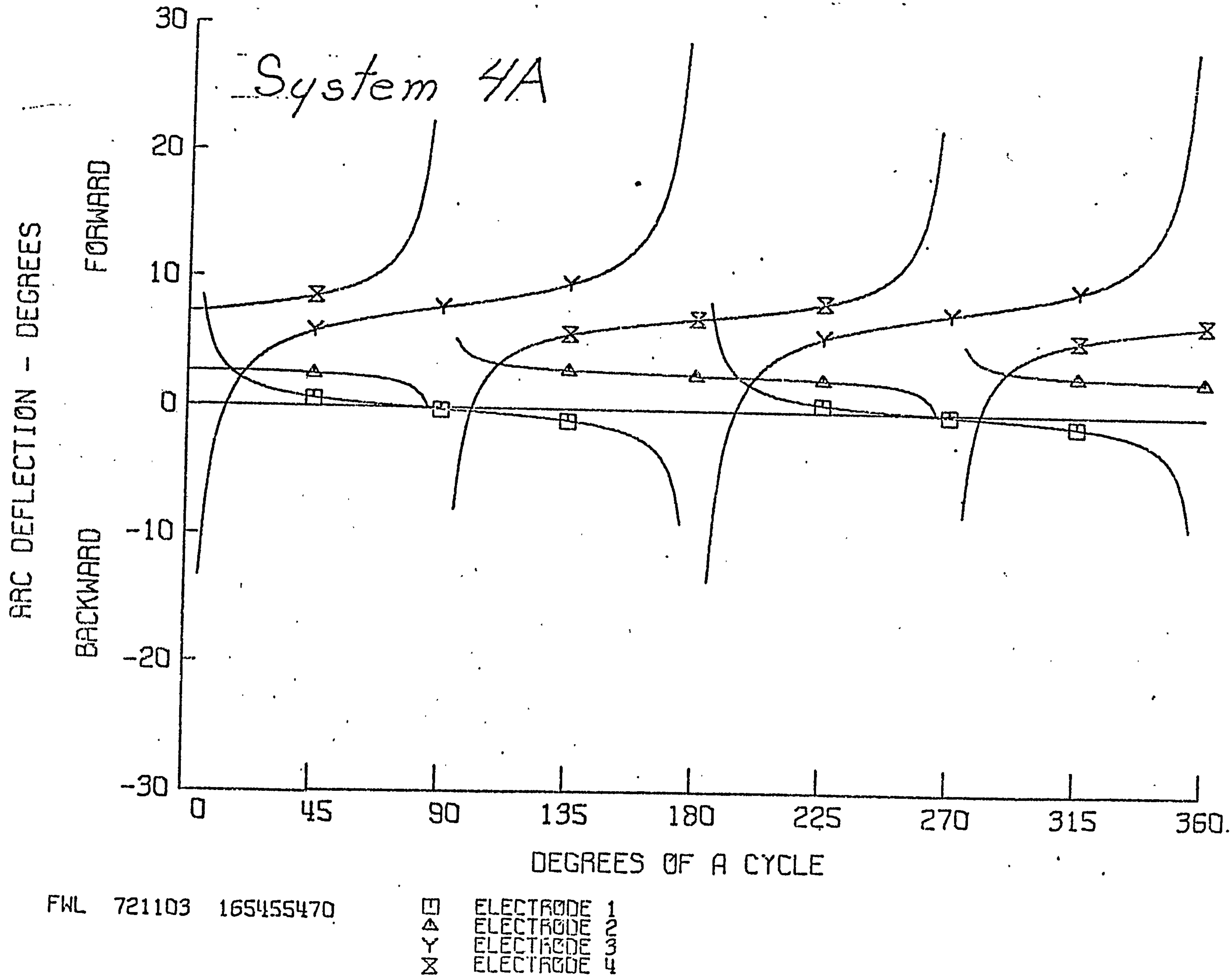


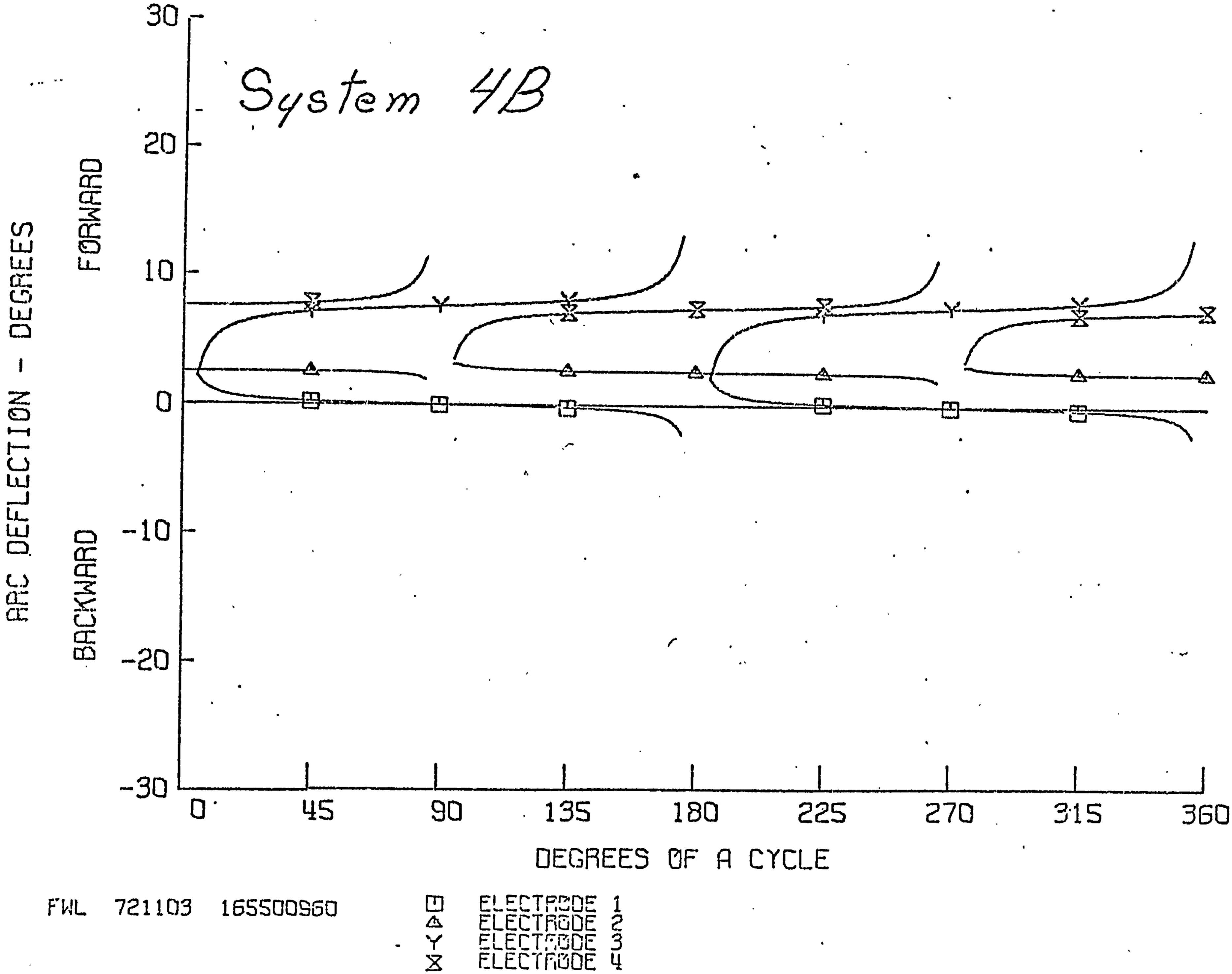
System 2A
ARC DEFLECTION - DEGREES
FORWARD
BACKWARD
30
20
10
0
-10
-20
-30
0
45
90
135
180
225
270
315
360
DEGREES OF A CYCLE
FNL 721106 095705900
ELECTRODE 1
ELECTRODE 2
ELECTRODE 4

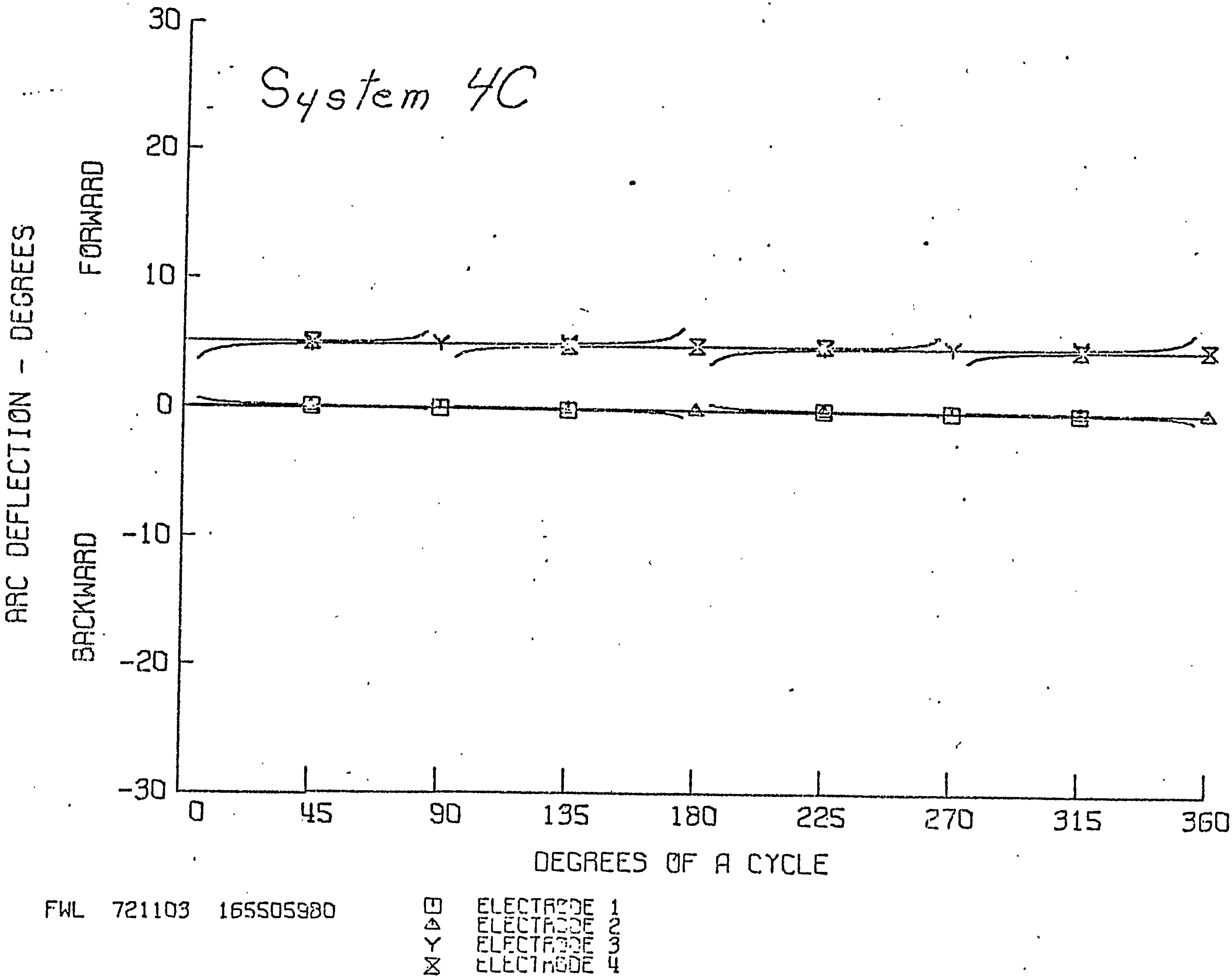


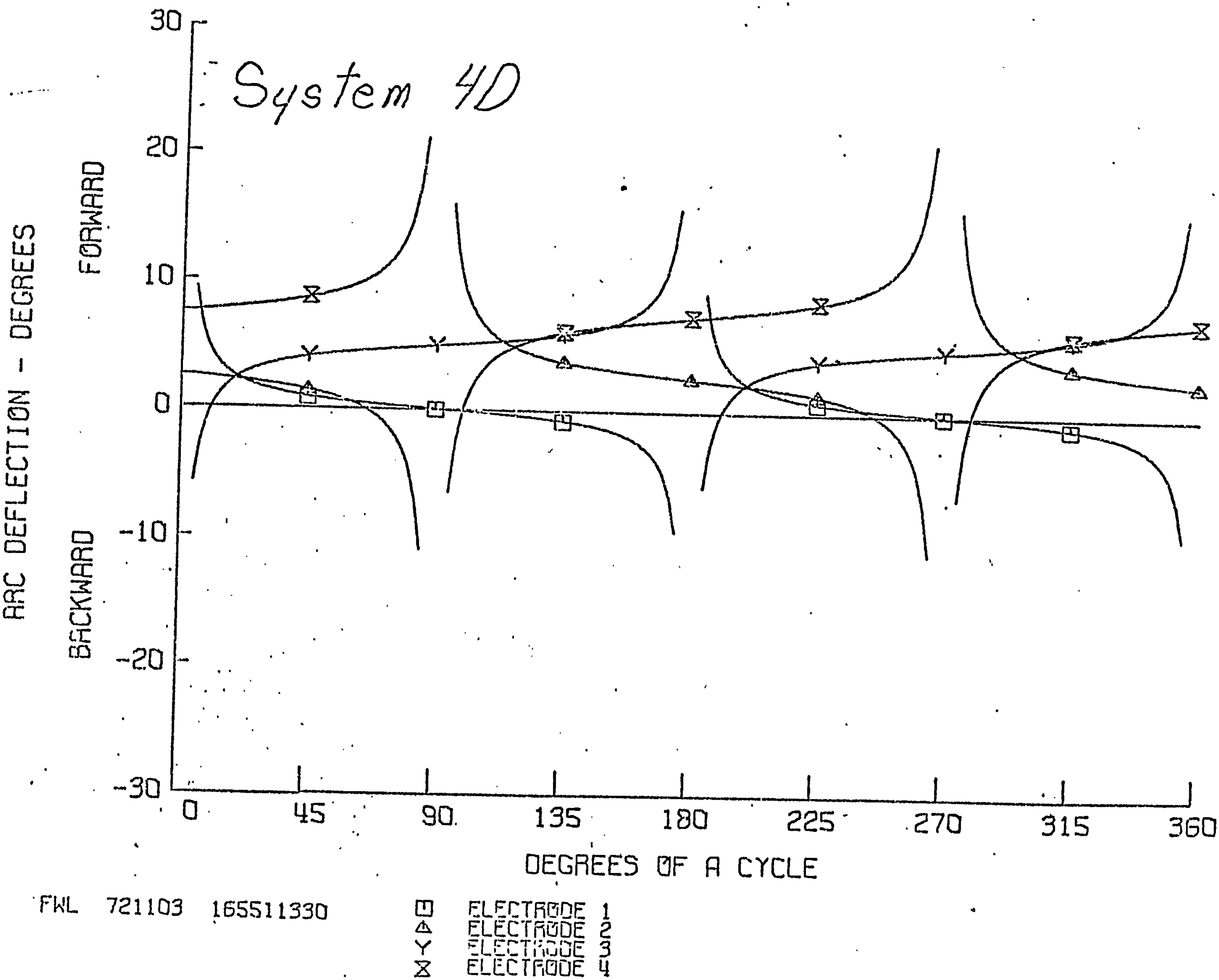
System 3A
ARC DEFLECTION - DEGREES
FØRWARD
BACKWARD
30
20
10
0
-10
-20
-30
0
45
90
135
180
225
270
315
360
DEGREES ØF A CYCLE
FWL 721103 165429530
ELECTRØDE 1
ELECTRØDE 2
ELECTRØDE 3
ELECTRØDE 4


System 3D
ARC DEFLECTION - DEGREES
FØRWARD
BACKWARD
30
20
10
0
-10
-20
-30
0
45
90
135
180
225
270
315
360
DEGREES ØF A CYCLE
FWL 721103 165448590
ELECTRODE 1
ELECTRODE 2
ELECTRODE 3
ELECTRODE 4


System 4A
30
20
10
0
-10
-20
-30
FORWARD
BACKWARD
ARC DEFLECTION - DEGREES
0
45
90
135
180
225
270
315
360.
DEGREES OF A CYCLE
FWL 721103 165455470
ELECTRODE 1
ELECTRODE 2
ELECTRODE 3
ELECTRODE 4


System 4B
ARC DEFLECTION - DEGREES
FØRWARD
BACKWARD
30
20
10
0
-10
-20
-30
0
45
90
135
180
225
270
315
360
DEGREES ØF A CYCLE
FWL 721103 165500960
ELECTRØDE 1
ELECTRØDE 2
ELECTRØDE 3
ELECTRØDE 4


System 4C
ARC DEFLECTION - DEGREES
FØRWARD
BACKWARD
30
20
10
0
-10
-20
-30
0
45
90
135
180
225
270
315
360
DEGREES ØF A CYCLE
FWL 721103 165505980
ELECTRØDE 1
ELECTRØDE 2
ELECTRØDE 3
ELECTRØDE 4


System 4D
ARC DEFLECTION - DEGREES
FORWARD
BACKWARD
30
20
10
0
-10
-20
-30
0
45
90
135
180
225
270
315
360
DEGREES OF A CYCLE
FWL 721103 165511330
ELECTRODE 1
ELECTRODE 2
ELECTRODE 3
ELECTRODE 4

Report No. 2

Project SP-1-1 Part 101
Contract No. 1560-721-1510-S/02-3764-C
One Side Welding Flux Development

PROGRAM OBJECTIVE

Presently available domestic submerged arc welding fluxes do not have the proper operating characteristics to produce one side helds of acceptable quality in heavy plate in ship fabrication. These fluxes also do not provide adequate impact resistance in heavy welds.

The objective of this program is to produce a flux suitable for manufacturing in the U.S. which, in conjunction with the multiwire system described in SP-101, Item 102, will provide satisfactory quality one side welds in 1 1/2 inch thick plate at speeds of 25-30 ipm and 50-60 ipm on thinner plate. When combined with a suitable wire, the mechanical properties of the weld joints must meet all requirements for ABS grades of carbon steel.

FIRST QUARTER ACHIEVEMENTS

1) A flux (977-14A) was developed which is capable of producing one side welds in 1 inch thick and 1 1/2 inch thick plate by using two AC multipowered electrodes on a flux copper backing system. Weld performance is similar to a commercially established foreign one side welding flux.

2) The foreign flux was extensively analyzed to determine its chemical composition.

3) One side welds were made in 1 and 1 1/2 inch thick plate with the foreign flux to verify the existing foreign welding techniques under-two electrode conditions.

SECOND QUARTER GOALS

The goals for the second quarter of this program are as follows:

1) Evaluate the experimental fluxes by making welds in 1 inch thick and 1 1/2 inch thick plate using the welding techniques established with foreign fluxes.

2) Evaluate the mechanical properties of the welds made with the experimental fluxes and several wires in ABS grade steels.

FULFILLMENT OF SECOND QUARTER GOALS

The 977-14A type flux was evaluated for two and four wire welding in 1 inch and 1 1/2 inch plate with varying ratios of iron powder to oxide constituents. Flux 977-14A and flux F-1 are comparable in performance using two wires. Both fluxes appear to deposit excess metal and a "cold" top bead contour when using four wires, leading to the test series with lower iron powder percentages. The low iron powder fluxes improve the top condition but are not as consistent in forming the bottom side of the weld.

All weld metal charpy data were obtained from the two wire welds which were made during the first quarter. These data from welds in ASTM Gd.A 515-70 plate, showed mechanical properties which would be generally acceptable for ABS H-2 type requirements. Mechanical properties obtained from four wire welds in 1 inch thick ABS Gd.B plate showed fluxes 977-14A and F-1 to be comparable with properties meeting H-3 type requirements. Mechanical properties obtained from four wire welds in 1 1/2 inch ABS Gd.C plate. however. met only H-2 type requirements with flux 977-14A.

TECHNICAL DISCUSSION

During the first quarter, one side welds were produced in 1 inch and 1 1/2 inch thick plate with flux 977-14A by using two AC multipowered electrodes on a flux copper backing bar. These welds had good top and-bottom bead shape and were comparable in appearance to welds produced with a foreign flux F-1. Because ship grade plate was unavailable at the time, ASTM A515 Gd.70 plate was used. Charpy V notch properties have now been obtained from these welds and the data is shown in Tables I and II.

The Charpy specimens were removed from two different areas of the welds. For removal of the specimens, the center line of the Charpy was located 3/8 inches below either the top or bottom surface of the plate. The specimens from the top of the weld are through an area of coarser microstructure whereas the bottom side specimens are from a finer microstructure area. The impact values from these welds meet filler metal Grade H-2 requirements but miss filler metal Grade H-3 requirements. As expected the values from the bottom of the welds are slightly higher and more consistent at lower temperatures than those from the top probably because of the finer microstructure.

During the second quarter a quantity of 1 inch and 1 1/2 inch thick ordinary strength hull structural steel was obtained from Bethlehem Steel. Chemical analysis categorized the 1 inch thick plate as ABS Grade B and the 1 1/2 inch thick plate as ABS Grade C. The analyses of the plates are shown in Table III.

Since one of the objectives of the program is to increase the welding deposition rate and welding speed by using more than two electrodes, a considerable effort was made to investigate the weld performance of the fluxes by using four electrodes. A number of welds were then made with four electrodes with both Flux 977-14A and F-1 by increasing the welding speed from 17 ipm to 40 ipm in 1 inch thick plate and from 14 ipm to 30 ipm in 1 1/2 inch thick plate. The same joint design as used for the two electrode welds was used for all the four electrode tests. Bead shape however proved to be unsatisfactory with both fluxes when tested under a variety of wire spacing and welding conditions. The main objection was too much weld metal and too crowned a bead on the top surface. This excess reinforcement condition occurred on welds made in both 1 inch and 1 1/2 inch thick plate.

Mechanical properties however, were obtained from a number of the welds and the data is shown in Tables IV to VI.

The impact properties from the weld made with Flux 977-14A in 1 inch ABS Grade B plate show that H-3 filler metal requirements can be obtained (Table IV). Tensile properties are also within the strength and ductility requirements for the higher strength EH Grade hull structural steel. The impact values obtained with Flux 977-14A also correlate well and compares favorably with those obtained with Flux F-1 (Table V). Tensile strength values are, however, lower with flux F-1.

In 1 1/2 inch Grade C plate substantially lower notch toughness values were obtained with Flux 977-14A as compared to those in one inch thick plate. This may be due to the much coarser microstructure which was noticeable in the top section of the heavier weld or it may be due to unstable operating conditions.

The photograph in Figure 1 shows a weld made in 1 1/2 inch plate with flux F-1 using the four electrode system that was investigated. The excess reinforcement that occurred on the top of the weld is readily apparent. The bottom side of the weld was incompletely filled and proved to be unsatisfactory. This same high crowned top bead was obtained with Flux 977-14A but the bottom was more uniform and considered acceptable. Increasing the travel speed to reduce top fill with Flux 977-14A resulted in insufficient bottom bead fill.

This high top bead with four electrodes results from an excessive contribution of iron from the flux because of a hotter flux puddle as well as possibly some added fill from the additional wires. In order to reduce the amount of weld metal contributed by the flux a number of fluxes were formulated which contained lower amounts of iron powder. Table VII lists two additional formulations out of a number that were investigated which contain lesser amounts of iron than Flux 977-14A. In these fluxes the non-metallic fluxing constituents were increased proportionately to the lower levels of iron but the manganese and silicon deoxidizers were maintained at a constant level.

The photograph in Figure 2 shows a weld in 1 1/2 inch thick plate which was made with Flux 977-39B containing 32% iron powder. The top of the bead is still overfilled but slightly less than that obtained with a higher iron containing flux. The bottom bead is almost completely formed.

In Figure 3 a weld is shown which was made with a flux containing 19% iron powder (977-39C). The top is flat and has good surface tie-in but the bottom is completely underfilled because of the lack of iron powder from the flux.

A weld made in one inch plate with four electrodes is shown in Figure 4. The flux contained 32% iron powder (977-39B). Overfill on the top bead is apparent as in the 1 1/2 in. plate but the bottom side is well shaped. This same general configuration was obtained with the original 977-14A flux which contained 43% iron powder. Since the main objection to this weld is excess metal on the top surface it was apparent that a simple means of decreasing the amount would be to eliminate one of the four electrodes.

Shown in Figure 5 is a weld that was made with a three wire system and a flux containing 32% iron powder. The top of the bead is reasonably flat and the total weld contains about the amount of metal that is desired. The bottom of the weld is also reasonably well shaped. This weld, however, suggests that an improvement in the bottom could be achieved with about the same top appearance by using the original 43% iron powder flux under three wire conditions. This will be investigated during the next quarter primarily to aid in flux development. The four wire arc phasing study will continue,to determine if weld parameters can correct the top side bead shape problem.

Also scheduled for investigation during the next quarter are modifications in the flux by means of deoxidizer changes in order to improve the notch toughness properties especially in 1 1/2 inch thick plate.

MECHANICAL PROPERTIES

Weld No. 076-16

Flux 977-14A

Grade A515 Plate, 1 in. thick

2 Electrodes, 3/16 in. dia. Linde 43

Welding Speed 17 ipm

IMPACT PROPERTIES

	Top of Weld			Bottom of Weld		
Temp. °F	CVN Ft-Lbs	Lateral Expansion (Mils)	% Shear	Ft-Lbs	Lateral Expansion (Mils)	% Shear
+72	41	43	40	42	50	60
+32	28	30	20	35	32	40
+14	24	24	20	26	28	30
-4	21	20	20	22	24	20
-40	11	11	10	14	14	10

TABLE I

MECHANICAL PROPERTIES

Weld No. 976-15

Flux 977-14A

Grade A515 Plate, 1 1/2 in thick

2 Electrodes, 3/16 in. dia. Linde. 43

Welding Speed 14 ipm

IMPACT PROPERTIES

	Top of Weld			Bottom of Weld		
Temp. °F	CVN Ft-Lbs	Lateral Expansion(Mils)	% Shear	Ft-Lbs	Lateral Expansion(Mils)	% Shear
+72	41	4 3	40	42	50	60
+32	28	30	2 0	35	32	40
+14	24	24	2 0	26	28	30
-4	21	20	20	22	24	20
-40	1 1	1 1	10	14	14	10

TABLE II

CHEMICAL ANALYSIS
OF PLATE

	ABS Gd. B 1 in. thick	ABS Gd. C 1 1/2 in. thick
C	0.20	0.21
S	0.031	0.022
P	0.010	0.015
Mn	1.03	0.72
Si	0.03	0.22
Cr	0.024	0.016
Mo	0.005	0.005
Cu	0.015	0.017
V	0.002	0.002
Zr	0.005	0.005
Ti	0.002	0.003
Al	0.005	0.052
Cb	0.005	0.005
Co	0.01	0.01
Sn	0.02	0.02
Pb	0.002	0.002

TABLE III

MECHANICAL PROPERTIES

Weld No. 976-22

Flux 977-14A

ABS Gd. B plate 1 in. thick

4 Electrodes, 3/16" dia. Linde 43

Welding Speed 40 ipm

IMPACT PROPERTIES

	Top of Weld			Bottom of Weld		
Temp. °F	CVN Ft-Lbs	Lateral Expansion (Mils)	% Shear	CVN Ft-Lbs	Lateral Expansion (Mils)	% Shear
+72	84	77	90	69	68	90
+32	72	67	80	62	61	80
+14	52	50	60	60	56	80
-4	46	48	50	40	39	40
-20	43	42	30	40	39	30
-40	10	12	10	8	9	10

ALL WELD METAL TENSILE PROPERTIES (0.505)

UTS (psi)	75,600
YS (psi)	54,700
Elongation %	28.4
Reduction of Area %	61.9

TABLE IV

MECHANICAL PROPERTIES

Weld No. 976-20

Flux F-1

ABS Gd. B plate 1 in. thick

4 Electrodes 3/16" dia. Linde 43

Welding Speed 40 ipm

IMPACT PROPERTIES

	Top of Weld			Bottom of Weld		
Temp. °F	CVN Ft-Lbs	Lateral Expansion (Mils)	% Shear	CVN Ft-Lbs	Lateral Expansion (Mils)	% Shear
+72	75	79	80	58	63	60
+32	52	59	60	51	59	50
+14	31	34	40	45	50	40
-4	42	46	30	51	52	40
-20	21	23	10	34	36	10
-40	12	13	10	35	36	10

ALL WELD METAL TENSILE PROPERTIES (0.505)

UTS (psi)	67,200
YS (psi)	43,300
Elongation (%)	29.9
Reduction of Area %	63.5

TABLE V

MECHANICAL PROPERTIES

Weld No. 976-18

Flux 977-14A

ABS Gd. C plate 1 1/2 in. thick

4 Electrodes, 3/16" dia. Linde 43

Welding Speed 30 ipm

IMPACT PROPERTIES

Top of Weld

Temp. °F	CVN Ft-Lbs	Lateral Expansion (Mils)	% Shear
+72	44	45	60
+32	25	25	40
+14	23	23	20
-4	20	22	20
-20	10	9	10
-40	6	6	10

TABLE VI

CHEMICAL COMPOSITION
OF EXPERIMENTAL FLUXES

Component	Flux No. 977-14A Percent	Flux No. 977-39B Percent	Flux No. 977-39C Percent
Iron	43.72	32.11	19.10
MgO	16.81	21.62	26.73
SiO_2	13.84	15.75	18.42
$CaCO_3$	8.26	10.63	13.14
CaO	1.12	1.45	1.79
Al_2O_3	2.90	3.74	4.62
CaF_2	3.10	3.98	4.93
Mn	4.54	4.57	4.57
Si	2.16	2.18	2.18
Na_2O	2.92	3.13	3.53
K_2O	0.62	0.80	0.99

TABLE VII

WELDING CONDITIONS

Weld No.	Flux	Wires	Plate	Electrode 1 Amps AC	Electrode 1 Volts	Electrode 2 Amps AC	Electrode 2 Volts	Electrode 3 Amps AC	Electrode 3 Volts	Electrode 4 Amps AC	Electrode 4 Volts	Spe ip:
976-16	977-14A	2 Linde 43, 3/16"	A515 1"	1225	35	950	48	--	--	--	--	17
976-15	977-14A	2 Linde 43, 3/16"	A515 1 1/2"	1450	36	1040	55	--	--	--	--	12
976-22	977-14A	4 Linde 43, 3/16"	ABS Gd.B 1"	1400	46	1100	39	1080	34	700	50	30
976-20	F-1	4 Linde 43, 3/16"	ABS Gd.B 1"	1300	45	1100	40	1000	40	900	47	30
976-18	977-14A	4 Linde 43, 3/16"	ABS Gd.C 1 1/2"	1400	40	1140	48	1400	43	1080	48	26
976-262	F-1	3 Linde 43, 3/16" 1 Linde 36, 1/4"	ABS Gd.C 1 1/2"	1675	41	1250	38	1060	40	940	45	30
976-263	977-39B	3 Linde 43, 3/16" 1 Linde 36, 1/4"	ABS Gd.C 1 1/2"	1675	41	1250	38	1060	40	940	45	30
976-251	977-39C	4 Linde 43, 3/16"	ABS Gd.C 1 1/2"	1500	41	1180	38	1060	40	940	43	30
976-27	977-39B	3 Linde 43, 3/16" 1 Linde 36, 1/4"	ABS Gd.B 1"	1675	41	1250	38	1060	40	940	43	40
976-271	977-39B	2 Linde 43, 3/16"	ABS Gd.B 1"	1675	41	1180	40	1000	44	--	--	40

TABLE VIII

WELD NO. 976-262

PLATE 1 1/2" THICK
ABS Gd. C

FLUX F-1

FOUR WIRE

30 IPM

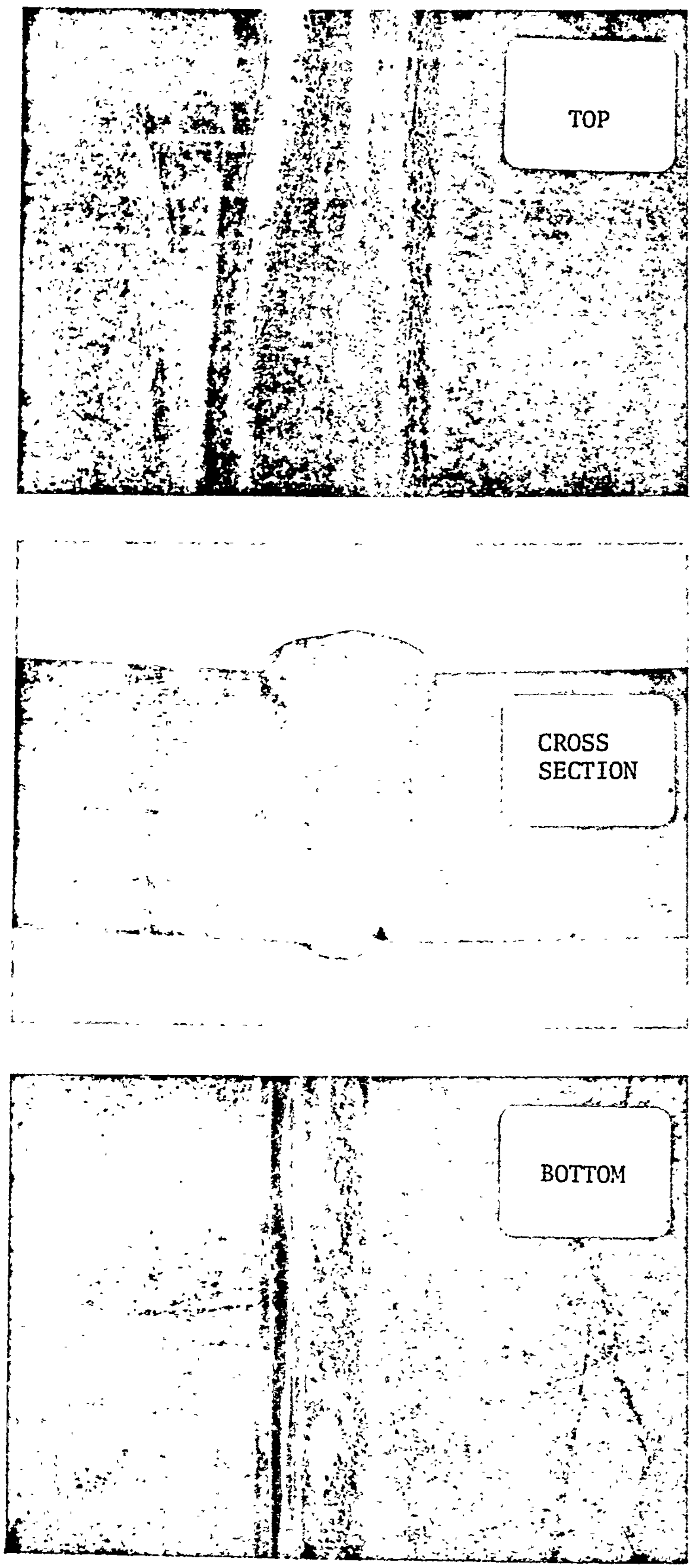
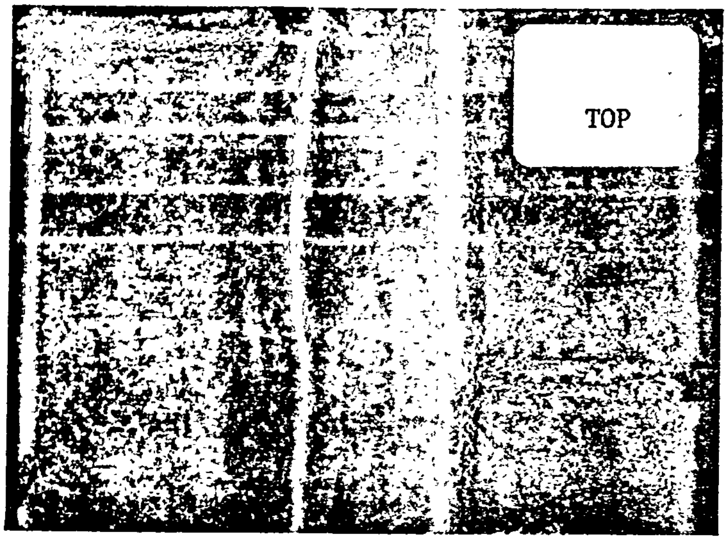


FIGURE 1



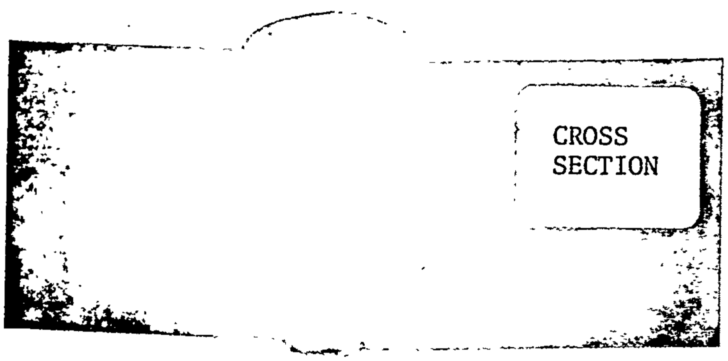
WELD NO. 976-263

PLATE 1 1/2" THICK
ABS Gd. C

FLUX 977-39B

FOUR WIRE

30 IPM



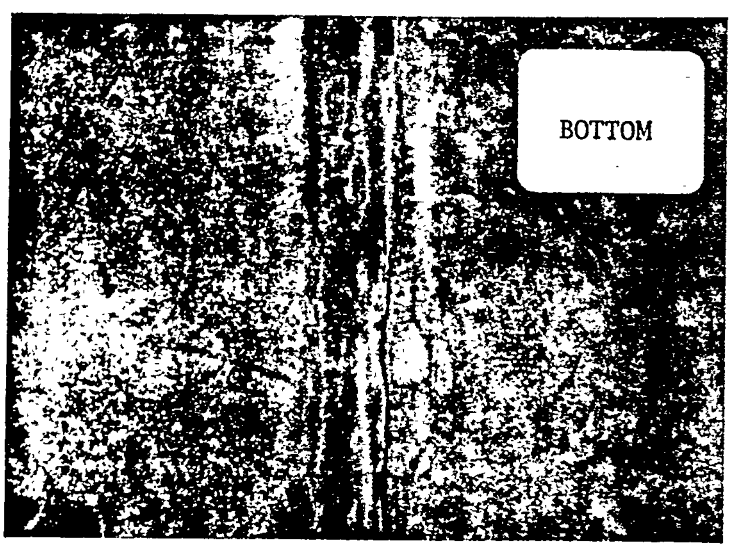


FIGURE 2

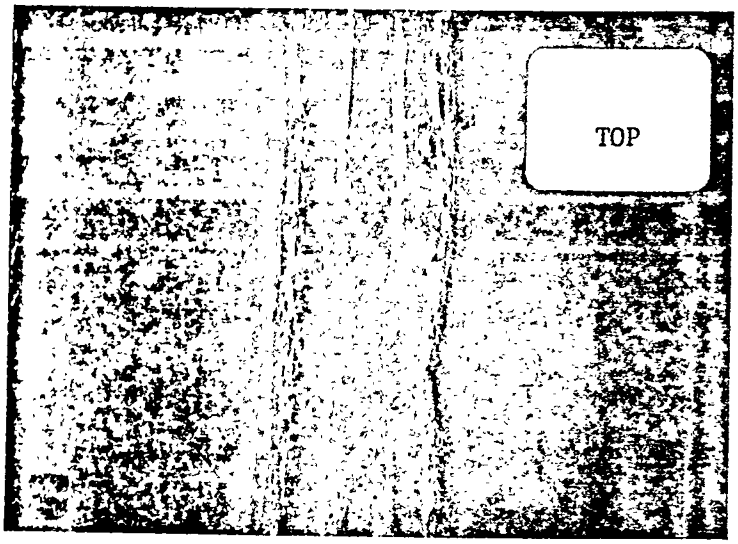
WELD NO. 976-251

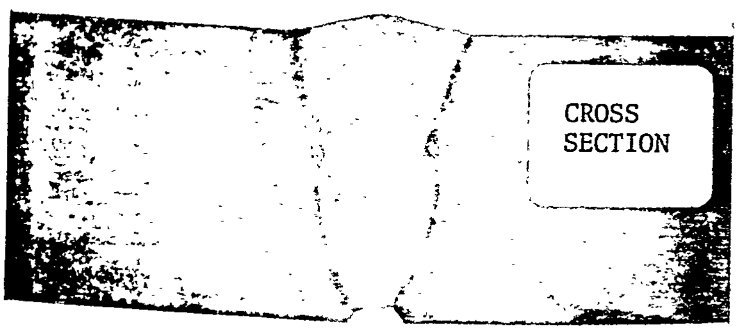
PLATE 1 1/2" THICK
ABS Gd. C

FLUX 977-39C

FOUR WIRE

30 IPM





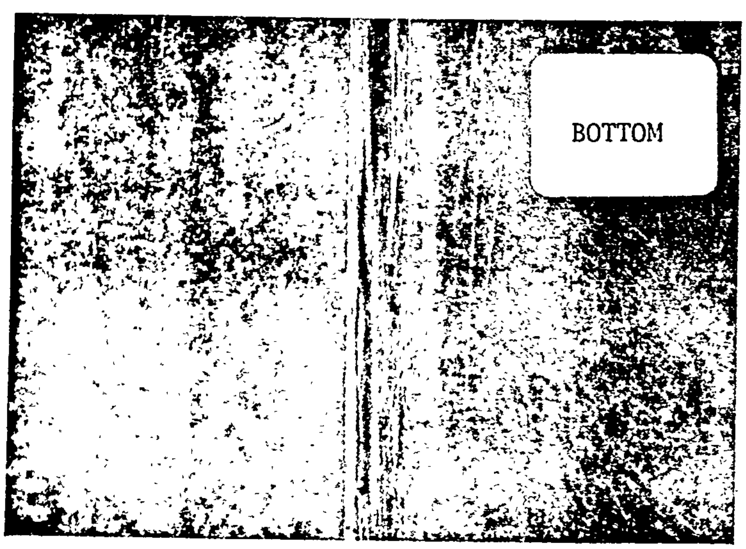


FIGURE 3

WELD NO. 976-27

PLATE 1" THICK
ABS Gd.

FLUX 977-39B

FOUR WIRE

40 IPM

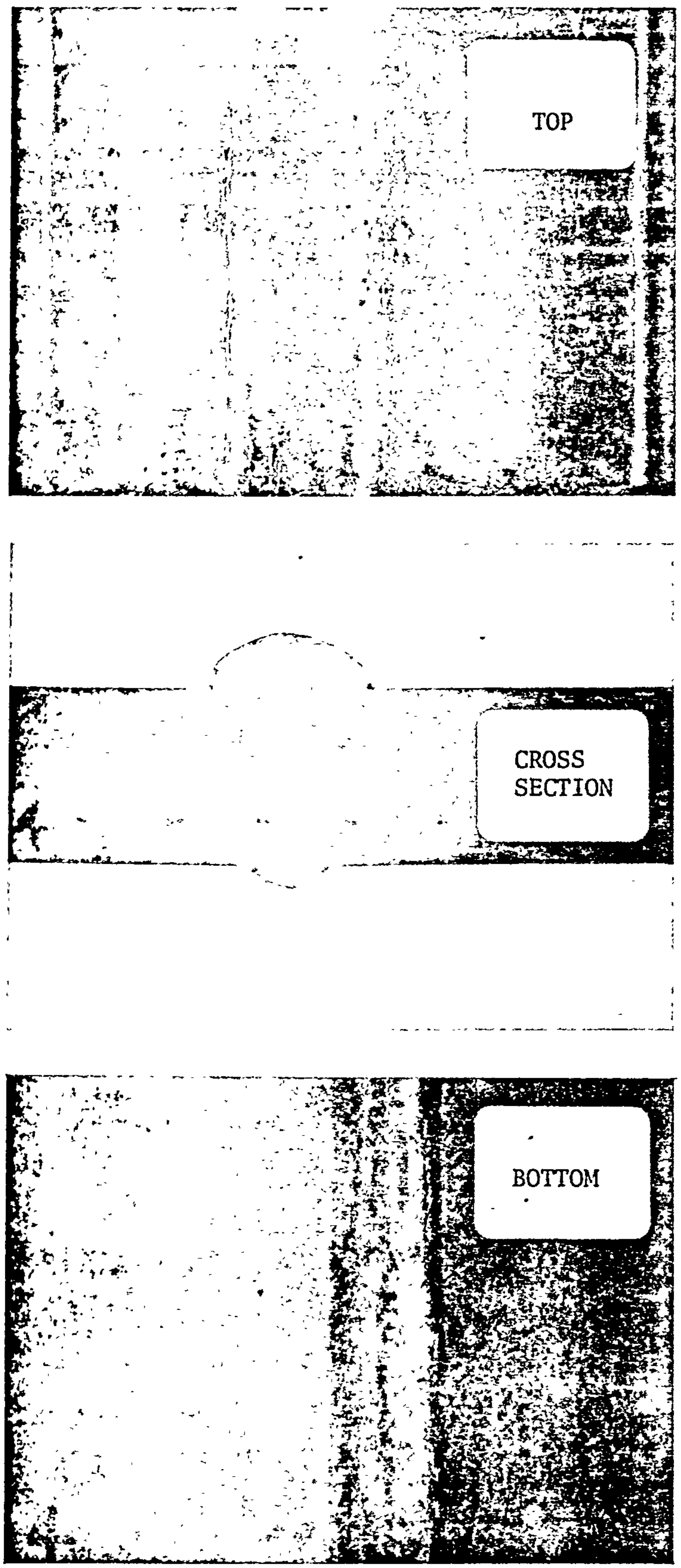


FIGURE 4

WELD NO. 976-271

PLATE 1" THICK
ABS Gd.

FLUX 977-39B

THREE WIRE

40 IPM

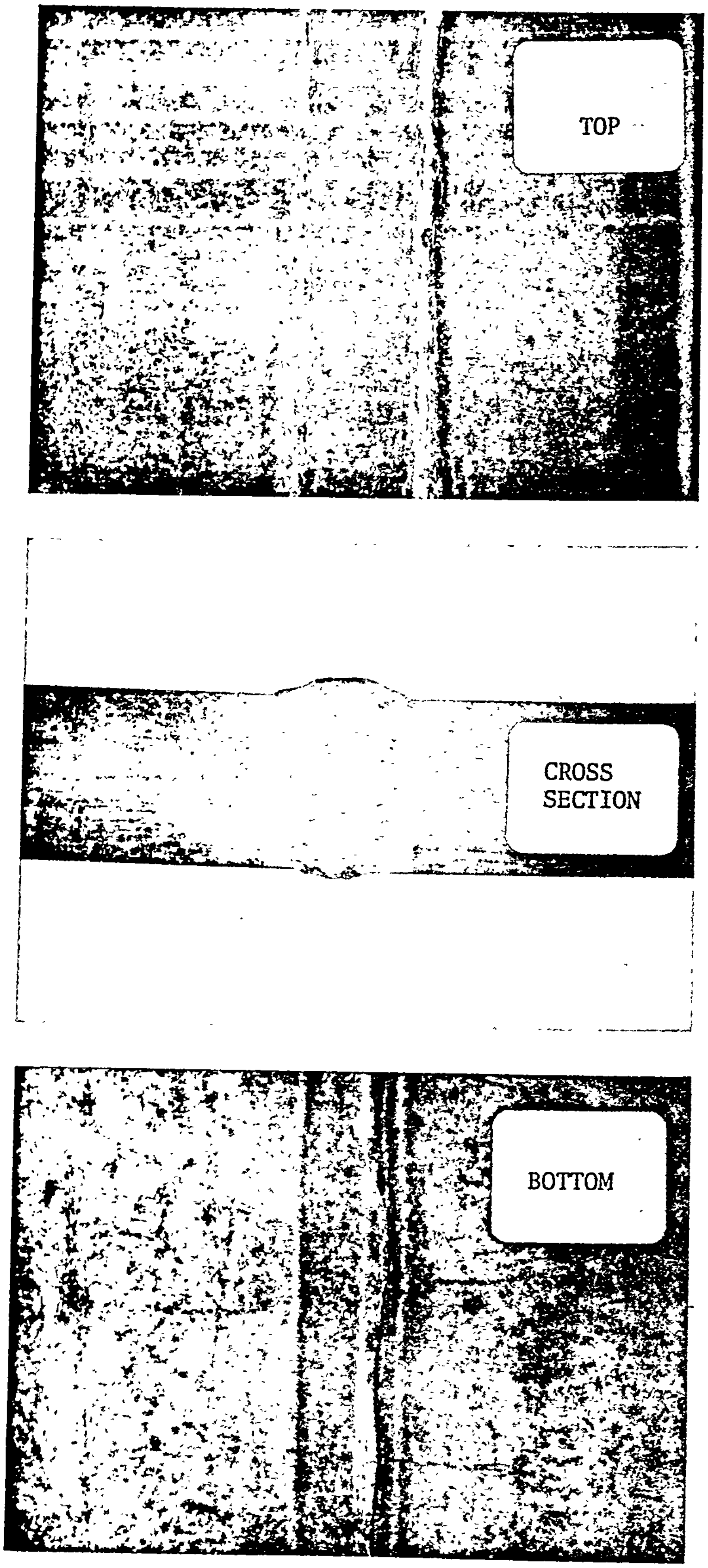


FIGURE 5

Report No. 2

Project SP-1-1 Part 102
Contract No. 1560-721-1511-S/02-3764-D
One Side Welding Multiple Arc Study

PROGRAM OBJECTIVE

To provide sufficiently high travel speeds for economical one-side welding of ship plates, a multi-electrode submerged arc system is necessary.

For the production of one side, one pass butt welds in 1 1/2" thick plate, even our presently existing three electrode systems will not be sufficient to achieve the desired 25 to 30 ipm travel speeds.

The goal of the program is to develop a four electrode welding system capable of depositing metal at the rate of 120 to 150 lbs/hr. A four electrode system operating at from 1,000 to 1,500 amps per electrode will provide the required deposition rate and should attain the welding speeds desired,

FIRST QUARTER ACHIEVEMENTS

As covered in the First Quarter report the two major goals were achieved.

1) The equipment required for making a four electrode weld was assembled.

2) A theoretical arc deflection analysis was conducted and completed. Of the sixteen separate variations of arc deflection systems analyzed two were selected for further evaluation.

SECOND QUARTER GOALS

1) Evaluate the systems selected in the First Quarter theoretical analysis for stability and performance in making one side welds in 1 1/2 inch thick plate. Select parameters to achieve travel speeds of over 25 ipm.

FULFILLMENT OF SECOND QUARTER GOALS

Welds were made with the four electrode system to evaluate stability and performance of the phasing systems analyzed in the First Quarter.

Most welds were made employing a pair of Scott connected electrodes with the rear Scott pair 180 deg. out of phase with the lead Scott pair.

This system recieved a concentrated effort since initial results were very encouraging and the system appears electrically very stable.

Using the above mentioned system, welds were made in 1" and 1 1/2" shipplate. Welding speeds in excess of the initial goals were achieved with moderate success in several plates. In 1" thick plate weld No. 976-27 (See Photo in Flux Development section) was welded at 40 ipm travel with good bottom and acceptable top weld results. Excessive weld reinforcement being the main weld objection.

In 1 1/2" plate, welds such as 976-263 (See Photo in Flux Development section) were produced at 30 ipm travel. Weld bottom-side shape and appearance was controllable and acceptable. Weld top side appearance although uniform was narrow and excessively high.

TECHNICAL DETAILS

One of the four electrode power phasing systems selected in the First Quarter was installed for the initial welding evaluation.

To obtain a record of the specific power phasing systems being evaluated and to assist in monitoring the electrical characteristics, a recording voltmeter was connected to the system. A Honeywell 1508 Visicorder was selected for 1) its high chart speed, 2) the number of channels available and 3) the range of response rates available. For this evaluation each electrode voltage was sensed and recorded. Applying open circuit voltage to each electrode it was possible to obtain a permanent record of the power phasing system being evaluated. See Figure 1 and 2 for photographs of recordings obtained of two of the arc power phasing systems evaluated.

Most of the welding during this reporting period was performed with a pair of Scott connected electrodes with the rear Scott pair 180 deg. out of phase with the lead Scott pair. Refer to Figure 1 for a graphical presentation and vector notation of this phasing system.

Over a number of welds, electrode spacings and current parameters this system has proven to be electrically quite stable. Several general observations can be made regarding achieving stable welding operation employing this one phasing system.

1) The best underbead formation and system stability is achieved with a closely spaced 1st and 2nd electrode, 3/4 to 1 inch.

2) The second pair of electrodes are most stable and provide the most uniform top side welds when spaced from 3 to 5 inches from the first pair.

3) The 4th electrode stability and final weld shape are most uniform when this electrode is spaced 2 to 3" behind the 3rd electrode.

4) Flux height and distribution are important to achieve minimum system flashing and best weld results. This is best achieved by using two flux dispensing systems. one at the front of the first two and the second in front of the rear pair of electrodes.

5) With this system achieving adequately wide and flat welds was most difficult and not satisfactorily achieved with the range of parameters and fluxes evaluated including flux F-1. Changing from the nominal 3/16" to both 1/4" and 1/8" diameter electrodes on the 4th electrode did not produce the desired, flat-wide top side welds.

During this arc study several differing flux systems were evaluated to determine if improved weld shape-could be achieved. These flux variations are covered in the flux development part of this report.

SPECIFIC PARAMETERS FOR WELDS IN 1" AND 1 1/2" PLATE

The following specific parameters used on two moderately successful welds will illustrate the nominal conditions necessary for production of good bottom side and sound but narrow tip side weld performance.

WELD NO. 976-27 IN 1" PLATE

Plate: 1" thick ABS
50° Inc. angle 21/32" deep, 3/32 nose
60° Inc. angle l/4" deep bottom vee.

Wire Configuration:

1st	5 deg. trailing	lst-2nd 7/8"
2nd	vertical	- 2nd-3rd 3 1/2"
3rd	12 deg. leading	3rd-4th 2 1/2"
4th	12 deg. leading	

Parameters:

	1st	2nd	3rd	4th
Amps	1675	1250	1060	940
Volts	41	38	40	43

Travel: 40 ipm

Flux: Exp. 976-39B

WELD NO. 976-263 IN 1 1/2" PLATE

Plate: 1 1/2" thick ABS
50° Inc. angle 1 1/8" deep, 3/16" nose
60° Inc. angle l/4" deep bottom vee.

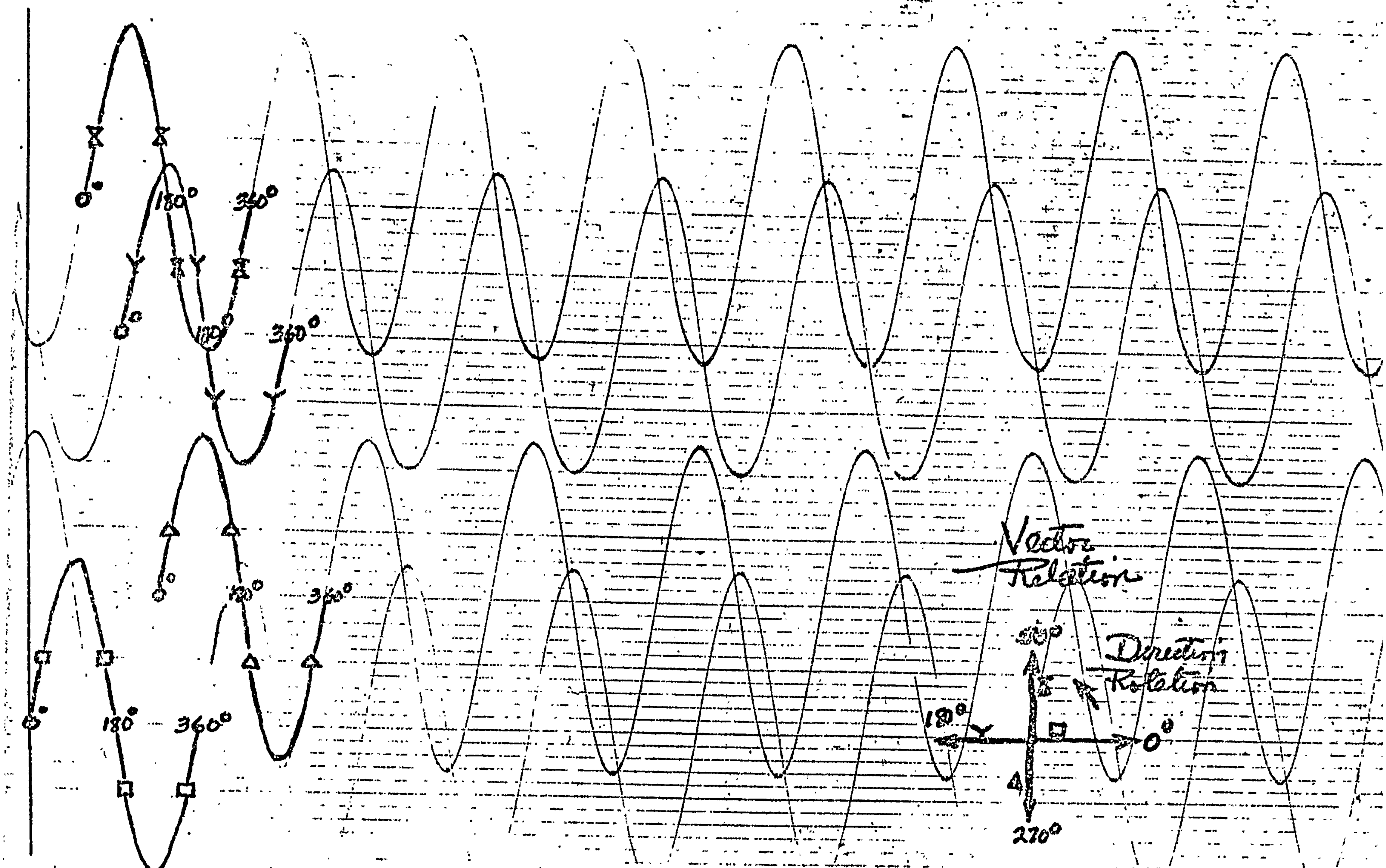
Wire Configuration & Parameters:

Same as 976-27 (above) except travel 30 ipm

Flux: Exp. 976-39B

To determine the exact nature of the arc interactions and to possibly ascertain the reason for the narrow, peaked top side welds, the four electrodes system will be photographed during the next quarter.

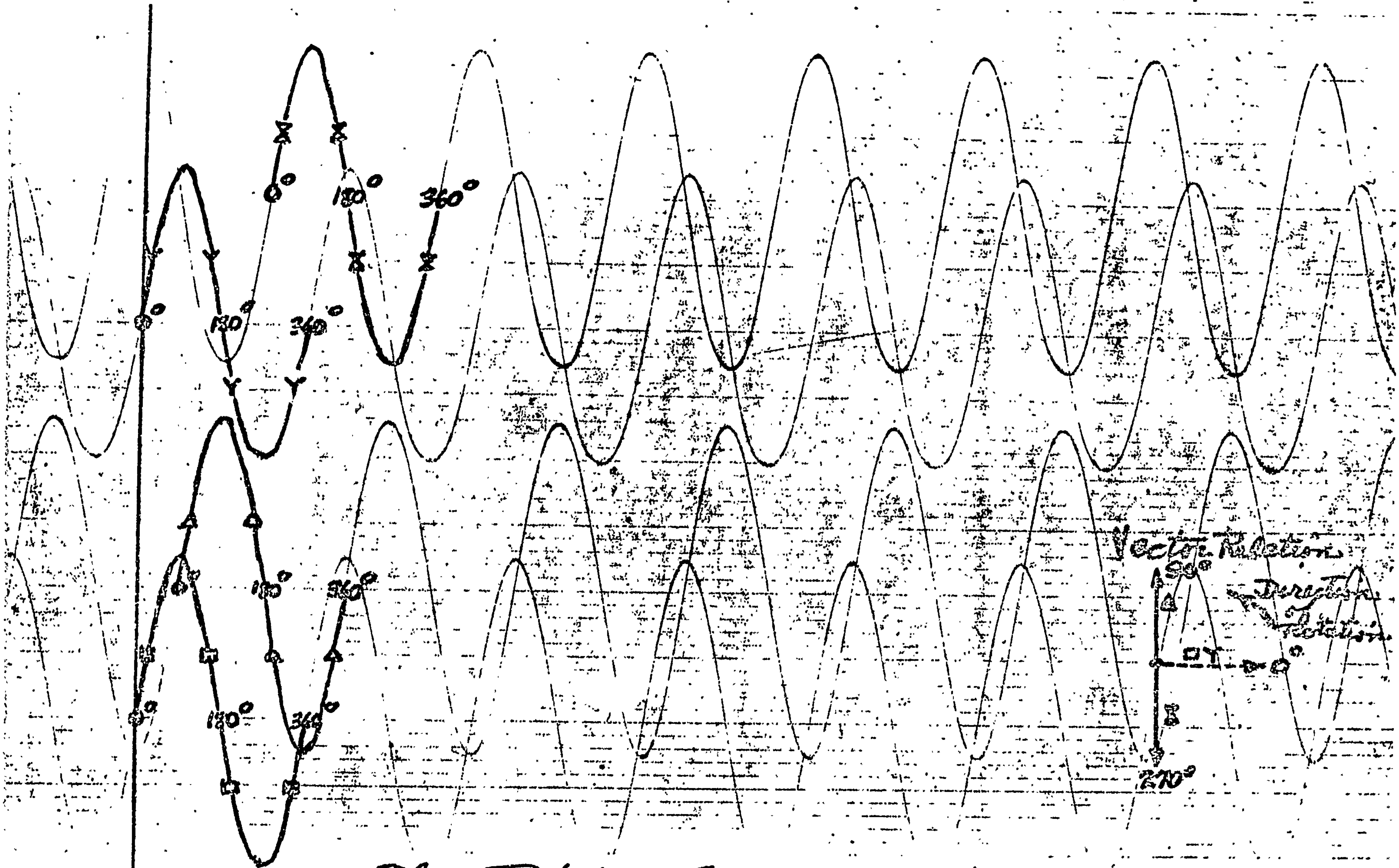
This will be performed by allowing the system to run out of flux for a short period. At least two arc power phasing systems will be evaluated in this manner.



JEM
3/1/73

Phase Rotation Electrodes 1,4,3,2
Open Circuit Voltage AC

Electrode	Legend
1	□
2	△
3	Y
4	X



Phase Rotation Electrodes 1, 3, 2, 4
Open Circuit Voltage AC

Electrode	Legend
1	□

JEM
3/1/73

Report No. 3

Project SP-1-1 Part 101
Contract No. 1560-721-1510-S/02-3764-C
One Side Welding Flux Development

PROGRAM OBJECTIVE

Presently available domestic submerged arc welding fluxes do not have the proper operating characteristics to produce one side welds of acceptable quality in heavy plate in ship fabrication. These fluxes also do not provide adequate impact resistance in heavy welds.

The objective of this program is to produce a flux suitable for manufacturing in the U.S. which, in conjunction with the multi-wire system described in SP-101, Item 102, will provide satisfactory quality one side welds in 1 1/2 inch thick plate at speeds of 25-30 ipm and 50-60 ipm on thinner plate. When combined with a suitable wire, the mechanical properties of the weld joints must meet all requirements for ABS grades of carbon steel. The attainment of producing satisfactory one side welds at these welding speeds, however, is dependent upon the successful establishment of a stable four electrode welding system. Results now indicate that a three wire welding system would be more easily adaptable. to commercial usage at slightly reduced welding speeds.

FIRST AND SECOND QUARTER ACHIEVEMENTS

As discussed in the first and second quarterly reports, several major accomplishments have been achieved.

1) A flux has been developed which is capable of producing one side welds in 1 inch thick and 1 1/2 inch thick plate by using multiple electrodes on a flux copper backing system.

2) Weld performance of the flux is comparable to a commercially established one side welding flux.

3) Welds have been made with two electrodes, three electrodes, and four electrodes using multi-powered AC systems. Good weld performance and bead shape have been obtained with two multi-powered AC electrodes. Arc stability and weld performance appears to be somewhat erratic using four electrodes which may be difficult to control under commercial fabrication conditions. with four electrodes the flux provides excess weld metal which results in a high and narrow top bead contour. The operability of three electrodes is being investigated and will be discussed in this report.

4) Mechanical properties obtained from two and four wire welds in 1 inch thick ABS Gd. B. plate showed the developed flux to be comparable to the foreign flux with properties meeting H-3 type requirements. Welds in 1 1/2 inch thick ABS Gd. C. plate with the developed flux gave mechanical properties meeting H-2 type requirements.

3RD QUARTER GOALS

The goals for the third quarter of this program are as follows:

1) Produce one-side welds in 1 1/2 inch thick plate using the best developed flux with the four electrode power connections investigated under Program SP-1-1, Item 102.

2) Investigate the three wire AC system for making one side welds with the best developed flux.

FULFILLMENT OF THIRD QUARTER GOALS

1) The performance characteristics of the developed fluxes using four AC powered electrodes were extensively discussed in the second quarter report. This investigation was continued during the third quarter using changes in phasing and the results are discussed in the adjoining arc study section of this report.

All the experiments with the four electrode systems resulted in welds which had a crowned and narrow top bead. From a commercial standpoint, this bead shape would be considered unacceptable.

2) Welds in 1 inch thick ABS Gd. B. plate using three electrodes show good bead contour with a reasonably flat top bead shape and good bottom bead shape. Mechanical properties with the developed flux No. 977-39B are slightly superior to those obtained with the foreign flux F-1 and will meet H-3 type requirements.

Welds made with three electrodes in 1 1/2 inch ABS Gd. C. plate are slightly underfilled on top but the bottom has good shape. Cross sections of the welds show good contour and tie in. Notch toughness properties meet only H-2 type requirements but are higher than those previously reported with four electrodes and are close to meeting the H-3 requirements.

DISCUSSION

Changes in the weld parameters and phasing connections using four electrodes has failed to show any significant improvement in the top bead shape as described in the second quarter report. The weld shown in Fig. 4 is typical of the configuration that was obtained under practically all four electrode welding conditions. The high crowned top bead resulted from fusing an excessive amount of flux which contributed a high level of molten metal to the top section of the weld deposit. As shown by the crossection; a narrow weld nugget was also obtained. This weld shape should be avoided because of the possibility of voids and entrapped slag particles in the center of the weld between the two solidification phases.

Because of the unsatisfactory bead shape experimentation with four electrodes was terminated. As mentioned in the last quarterly report, a more acceptable bead configuration was achieved using a three electrode system at slightly reduced welding speeds.

The welds which will be discussed in this report were produced using Scott connected lead and middle electrodes with the third electrode connected separately but in phase with the lead electrode. Welding conditions are given in Table 1. The developed flux which was used for the welds described is identified as 977-39B. This flux contains approximately 32% iron powder, and was chosen on the basis of best overall weld shape and performance using the three electrode system. The flux composition can be compared to the foreign flux which contains approximately 47% iron powder (Table VI).

The photographic Fig. 1 shows a weld made in 1 inch thick plate using flux 977-39B. The top side of the weld has sufficient width, good edge tie in and adequate fill to be considered commercially acceptable. The underbead is also well formed and has good edge appearance. Crossectional nugget shape has a single Vee appearance through the width of the plate which would favor reproducibility of sound welds deposit. Slag removal from the welds with flux 977-39B was considered good. The slag actually came off without any need for chipping from both the top and bottom side of the weld.

A similar weld deposit was obtained under the same welding conditions in one inch thick plate with the foreign flux F-1 (Fig. 2). The top of the bead, however, is slightly higher and more crowned because of the higher level of iron powder in the flux. Slag removal was acceptable, however, the fused slag did not come off the underbead as easily as flux 977-39B.

The mechanical properties from the one inch thick welds are given in Tables II and III. The impact properties are slightly higher in the weld made with flux 977-39B although both fluxes give charpy values meeting H-3 filler metal requirements (38 ft. lbs, at +14° or 20 ft. lbs. at -22°F).

Tensile properties of the weld with flux 977-39B are also within the strength and ductility requirements for the higher strength EH Grade hull structural steel (TS-71-90 KSI, YS-51 KSI min., El. -22%). Tensile strength values are, however, lower with flux F-1 and are less than the EH Grade requirements. Similar lower strength values were also obtained in the four electrode welds using flux F-1 as also reported in the last progress report.

The chemistry of the two weld metal deposits (Table V) provides an explanation for the differences in strength. Manganese and silicon are higher in the weld made with Flux 977-39B otherwise the chemistries are almost identical. This is due to the higher level and combined source of a manganese and silicon deoxidizer used in formulating flux 977-39B (Table VI). Analysis of flux F-1 indicated FeMn as being the only deoxidizing and strengthening constituent and at a much lower level (See first quarter report). Preliminary tests of flux 977-39B with FeMn substituted for the FeMnSi constituent resulted in poorer performance characteristics.

The photograph in Fig. 3 shows a weld made in 1 1/2 inch ABS Grade C plate with flux 977-39B using the same three wire welding conditions as for the one inch plate except slower travel speed. The crossection shows an excellently formed nugget with symmetrical sides which is conducive to defect free welds. Weld metal drop through on the bottom side is sufficient, however, the top side requires a slight addition of fill. A higher burn off rate on the trail electrode should give the necessary improvement.

Weld metal chemistry of the 1 1/2 inch welds as shown in Table V is in general agreement with the 1 inch weld. The slightly higher aluminum content apparently reflects pick-up from dilution of the Grade C plate which is aluminum killed (See Table VII).

Lower notch toughness values were obtained (Table III) as compared to the 1 inch thick weld but they are close to meeting the H-3 requirements. The tensile properties, however, meet the H-3 requirements.

Other phase connections are being investigated with three electrodes and these show more stable arc action. Only minor revisions in the flux are planned during the next and last quarter and these will be directed towards improving the notch toughness properties in 1 1/2 inch thick plate.

?

WELDING CONDITIONS

Weld No.	976-34	976-341	976-342
Plate	1" ABS Gd. B.	1" ABS Gd. B.	1 1/2" ABS Gd. B.
Flux	977-39B	F-1	977-39B
Wires	2 Linde 80, 3/16"	2 Linde 80, 3/16"	2 Linde 80, 3/16"
	1 Linde 36, 1/4"	1 Linde 36, 1/4"	1 Linde 36, 1/4"
Electrode 1			
Amps AC	1475	1475	1475
Volts	44	44	44
Electrode 2			
Amps AC	1150	1150	1150
Volts	42	42	42
Electrode 3			
Amps AC	1000	1000	1000
Volts	46	46	46
Travel Speed ipm	28	28	22

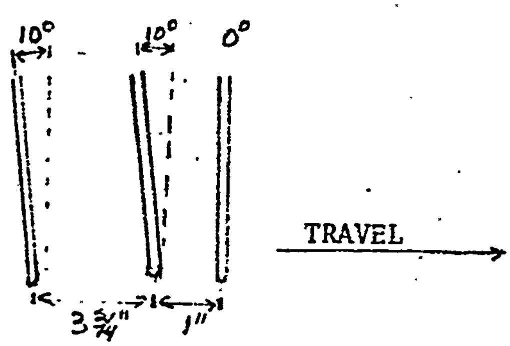


TABLE 1

MECHANICAL PROPERTIES

Weld No. 976-34

Flux 977-39 B

Plate - ABS Gd. B. - 1 in. thick

3 Electrodes

Welding Speed - 28 ipm

IMPACT PROPERTIES

	Top of Weld			Bottom of Weld		
Temp. °F	CVN Ft-Lbs	Lateral Expansion (Mils)	% Shear	CVN Ft-Lbs	Lateral Expansion (Mils)	% Shear
+72	73	67	80	83	78	90
+32	60	58	60	52	51	60
+14	35	35	40	51	48	50
-4	32	34	40	49	48	50
-20	31	32	30	36	35	40
-40	20	22	20	39	37	30

ALL WELD METAL TENSILE PROPERTIES (0.505)

UTS (psi)	82,900
YS (psi)	63,200
Elongation (%)	25.1
Reduction of Area %	61.4

TABLE II

MECHANICAL PROPERTIES

Weld No. 976-20

Flux F-1

Plate - ABS Gd. B. - 1 in. thick

3 Electrodes

Welding Speed - 28 ipm

IMPACT PROPERTIES

	Top of Weld			Bottom of Weld		
Temp. °F	CVN Ft-Lbs	Lateral Expansion(Mils	% Shear	CVN Ft-Lbs	Lateral Expansion (Mils)	% Shear
+72	60	63	80	58	65	70
+32	52	60	60	17	22	20
+14	23	.28	30	47	51	50
-4	28	31	20	29	31	30
-20	28	29	20	28	29	20
-40	20	20	10	15	15	10

ALL WELD METAL TENSILE PROPERTIES (0.505)

UTS[psi)	70,500
YS (psi)	48,700
Elongation (%)	25.6
Reduction of Area %	61.5

TABLE III

MECHANICAL PROPERTIES

Weld No. 976-342

Flux 977-39B

Plate - ABS Gd. C. -1 1/2 in. thick

3 Electrodes

Welding Speed -22 ipm

IMPACT PROPERTIES

Temp. %F	Top of Weld CVN Ft-Lbs	Top of Weld Lateral Expansion(Mils)	Top of Weld % Shear	Bottom of Weld CVN Ft-Lbs-	Bottom of Weld Lateral Expansion(Mils)	Bottom of Weld % Shea
+72	54	53	60	63	53	70
+ 3 2	41	40	40	44	41	40
+14	27	2 9	30	41	38	40
-4	18	22	2 0	27	27	30
-20	18	1 8	2 0	24	2 4	20
-40	10.3	9	10	9	9	10

ALL WELD METAL TENSILE PROPERTIES (0.505)

UTS(psi)	85,200
YS (psi)	63,900
Elongation (%)	24.3
Reduction of Area %	58.7

TABLE IV

WELD METAL ANALYSIS

	Weld 976-34 1" ABS Gd. B. Flux 977-39B	Weld 976-341 1" ABS Gd. B. Flux F-1	Weld 976-342 1 1/2" ABS Gd. C. Flux 977-39B
C	0.14	0.14	0.15
S	0.026	0.025	0.019
P	0.012	0.012	0.013
Mn	1.51	1.03	1.42
Si	0.31	0.18	0.45
Ni	0.016	0.016	0.016
Cr	0.031	0.029	0.029
Mo	0.010	0.009	0.011
Cu	0.080	0.064	0.076
V	0.006	0.002	0.009
Ti	0.003	0.003	0.003
Zr	0.004	0.004	0.004
Al	0.007	0.009	0.021
Cb	0.005	0.005	0.005
Pb	0.002	0.002	0.002

TABLE V

FLUX COMPOSITION

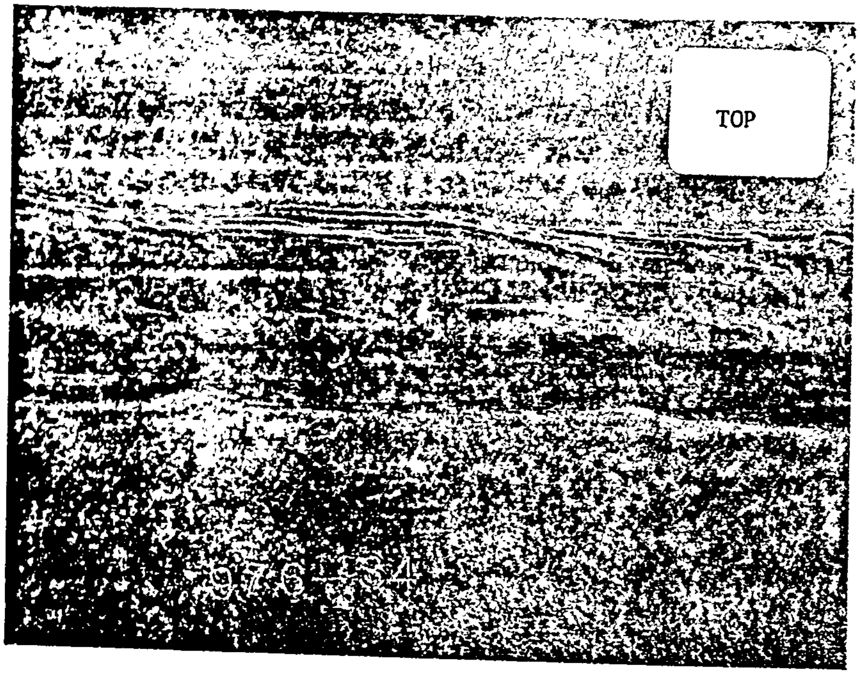
Component	Flux 977-39B Percent	Flux F-1 Percent
Iron	32.11	46.8
MgO	21.62	15.2
SiO_2	15.75	15.1
$CaCO_3$	10.63	8.6
CaO	1.45	2.1
Al_2O_3	3.74	3.8
CaF_2	3.98	3.3
Mn	4.57	2.6
Si	2.18	---
Na_2O	3.13	1.6
K_2O	0.80	0.13

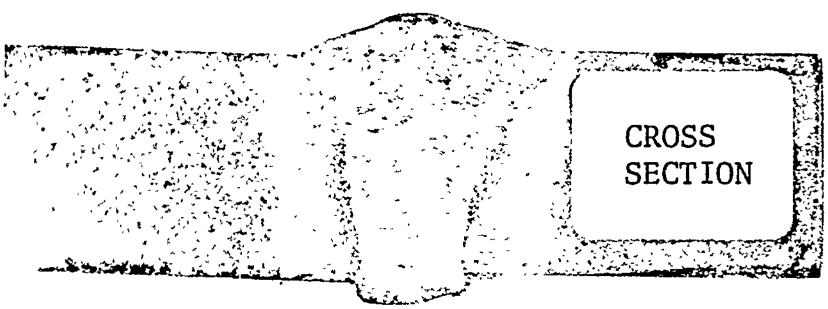
TABLE VI

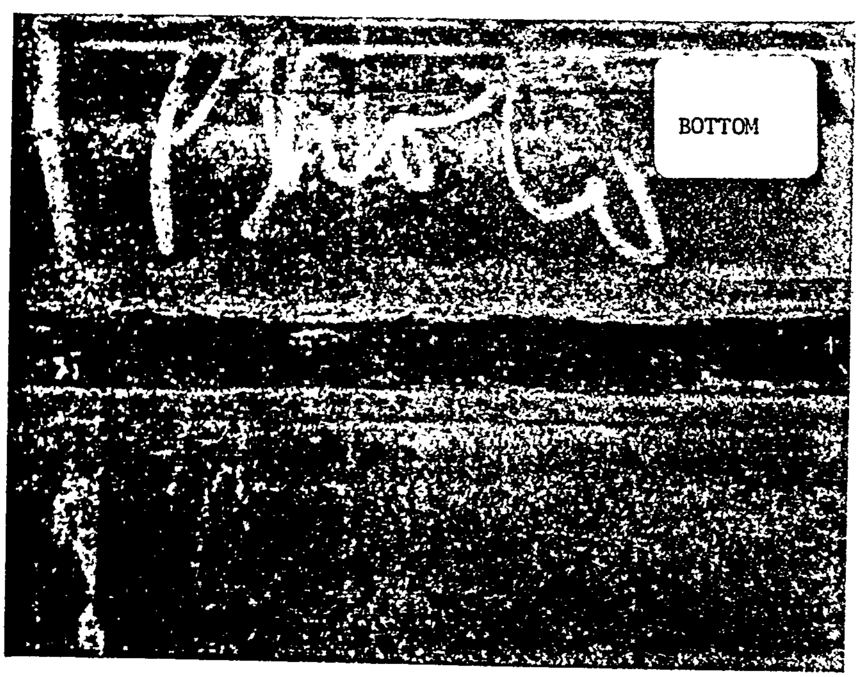
CHEMICAL ANALYSIS
OF PLATE

	ABS Gd. B 1 in. thick	ABS Gd. C 1 1/2 in. thick
C	0.20	0.21
S	0.031	0.022
P	0.010	0.015
Mn	1.03	0.72
Si	0.03	0.22
Cr	0.024	0.016
Mo	0.005	0.005
Cu	0.015	0.017
V	0.002	0.002
Zr	0.005	0.005
Ti	0.002	0.003
Al	0.005	0.052
Cb	0.005	0.005
Co	0.01	0.01
Sn	0.02	0.02
Pb	0.002	0.002

TABLE VII







WELD NO. 976-34

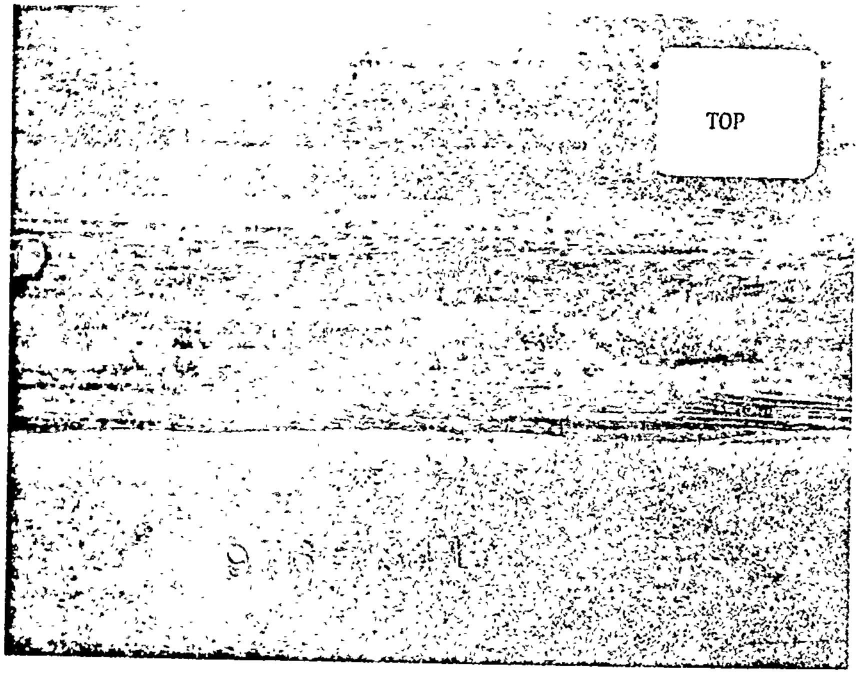
PLATE 1" THICK
ABS Gd. B

FLUX 965-39B

THREE WIRE

28 IPM

FIGURE 1



WELD NO. 976-341

PLATE 1" THICK
ABS Gd. B

FLUX F-1

THREE WIRE

28 IPM

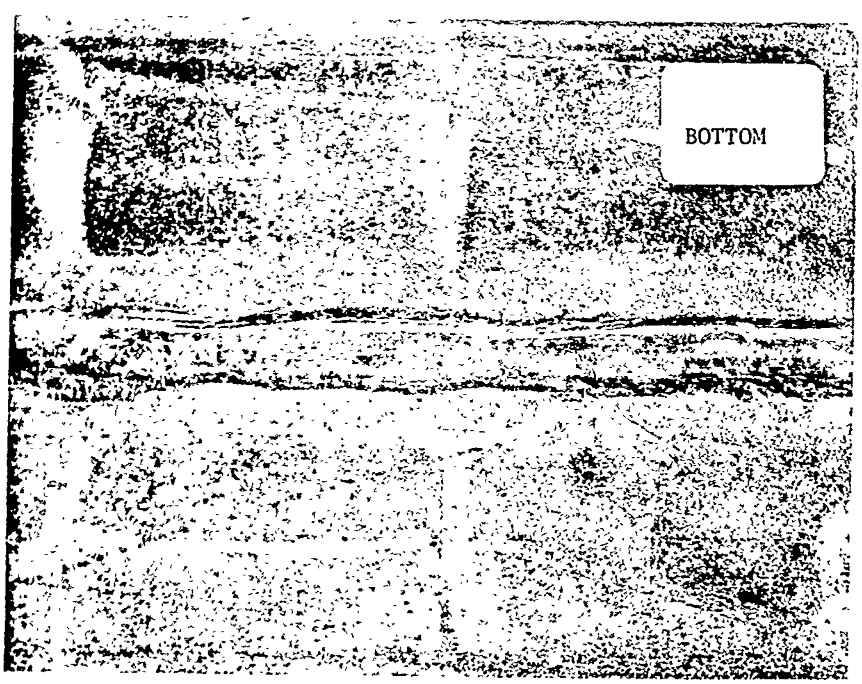
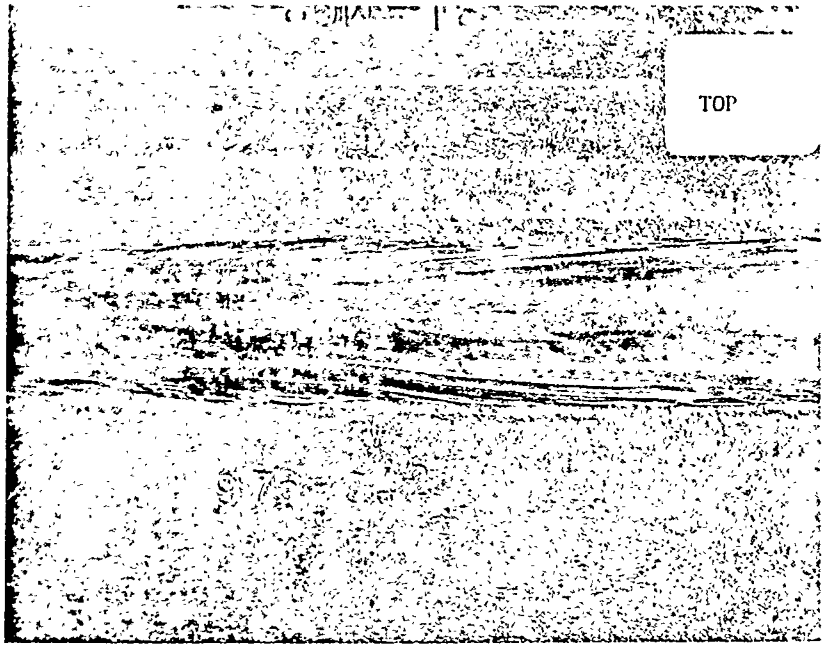


FIGURE 2



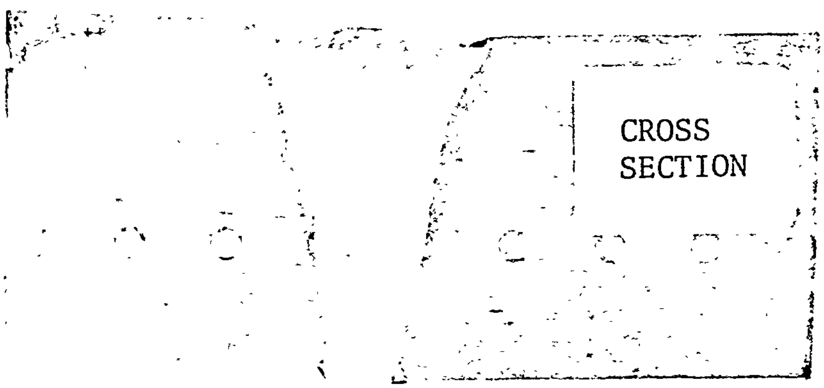
WELD NO. 976-342

PLATE 1 1/2" THICK
ABS Gd. B

FLUX 965-39B

THREE WIRE

22 IPM



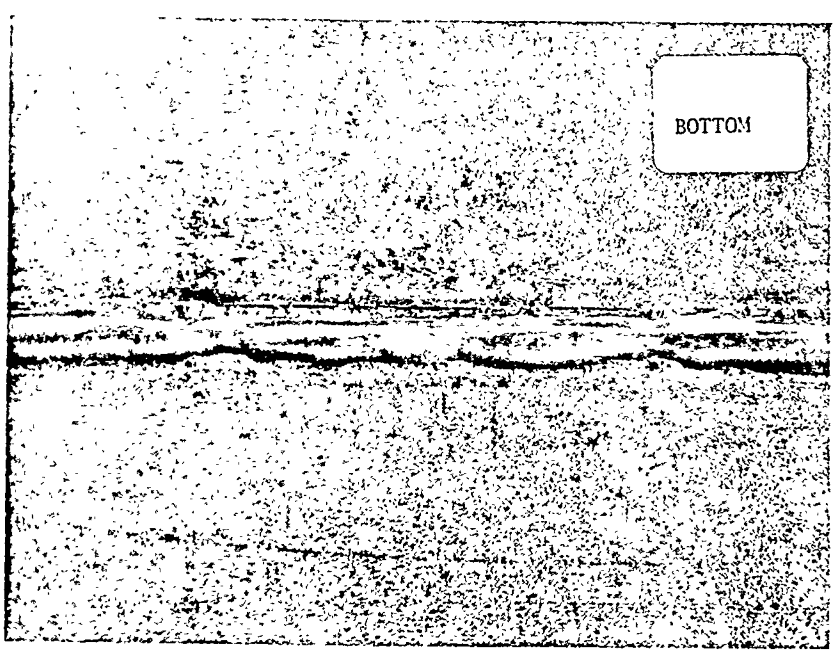


FIGURE 3

WELD NO. 976-27

PLATE 1" THICK
ABS Gd.

FLUX 977-39B

FOUR WIRE

40 IPM

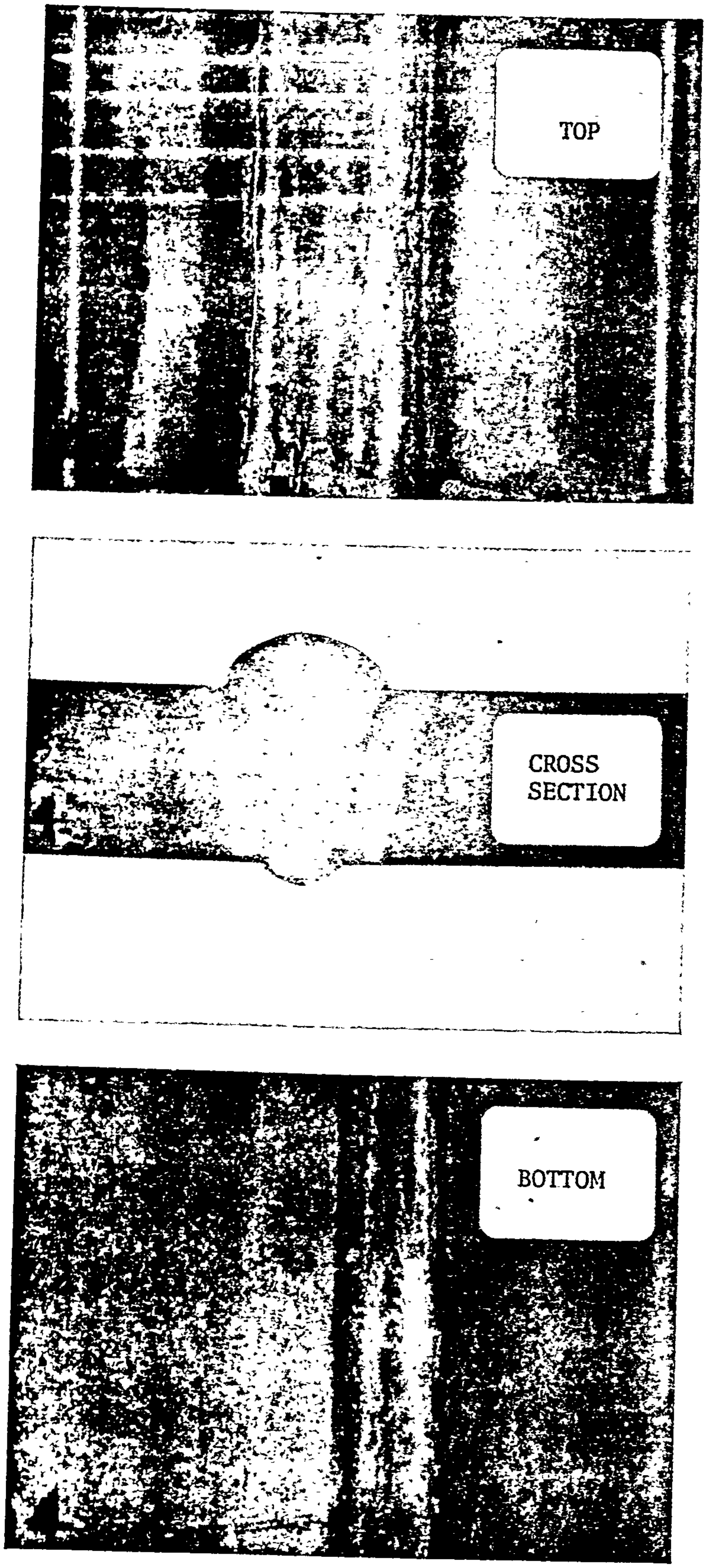


FIGURE 4

Report No. 3

Project SP-1-1 Part 102

Contract No. l560-721-lSll-S/02-3764-D

One Side Welding Multiple Arc Study

PROGRAM OBJECTIVES

To provide sufficiently high travel speeds for economical one-side welding of ship plates, a multi-electrode submerged arc system is necessary.

For the production of one-side, one pass butt welds in 1 1/2" thick plate, even our presently existing three electrode system will not be sufficient to achieve the desired 25 to 30 ipm travel speeds.

The initial program goal was to develop a four electrode system operating at from 1,000 to 1,500 amps per electrode to provide the desired deposition rate and attain the welding speeds desired.

After an encouraging lead from last quarter's work, and discussions of the four wire welding goals efforts at making three wire welds were pursued in the last quarter of this reporting period. As agreed the program goal welding speeds will be reduced to 25 to 30 ipm for welding 1" thick plate.

FIRST AND SECOND QUARTER ACHIEVEMENTS

As covered in the First and Second Quarter reports several major goals were accomplished:

1) After assembling the welding equipment a theoretical arc deflection analysis was conducted and completed. Of the sixteen separate variations of system parameters analyzed two were selected for further study.

2) One of the above power phasing systems (referred to as 4D; a pair of Scott connected electrodes followed by another Scott connected electrode pair 180 deg. out of phase with the lead pair) was used to make an extensive series of welds in 1" and 1 1/2" thick plates.

3) In the above series of experiments weld speeds exceeding the initial goals were achieved. Weld bottom side results were satisfactory, however, top surface beads had excess reinforcement and were somewhat irregular.

THIRD QUARTER GOALS

1) Make 4 wire welds with the second power phasing system defined in the 1st Quarter theoretical analysis, system 3D.

2) Work with Bethlehem Ship personnel for several days to evaluate previously tested 4 wire systems.

3) Take high speed motion pictures of arcs operating from several power phasing systems in air.

4) With a change in emphasis in the last part of this reporting period, develop 3 wire welding parameters.

FULFILLMENT OF THIRD QUARTER GOALS

A weld was made with the 120 deg., 60 deg. power phasing, system 3D. weld results were similar to the double Scott 4D system and not totally satisfactory.

With the assistance of two engineers from Bethlehem Steel Shipyard, Sparrows Point, Maryland, an evaluation of four electrode parameters previously evaluated at the shipyard was carried out over a two-day period. Top weld appearance with four electrodes was still excessively high, narrow and somewhat irregular.

A high speed motion picture study of the four electrodes was conducted for several welding power phasing systems.

Work was begun to optimize three electrode welding procedures.

TECHNICAL DETAILS

The second power phasing system determined in the theoretical arc deflection study as a candidate for good operation was evaluated. This power system, designated as 3D, is shown below:

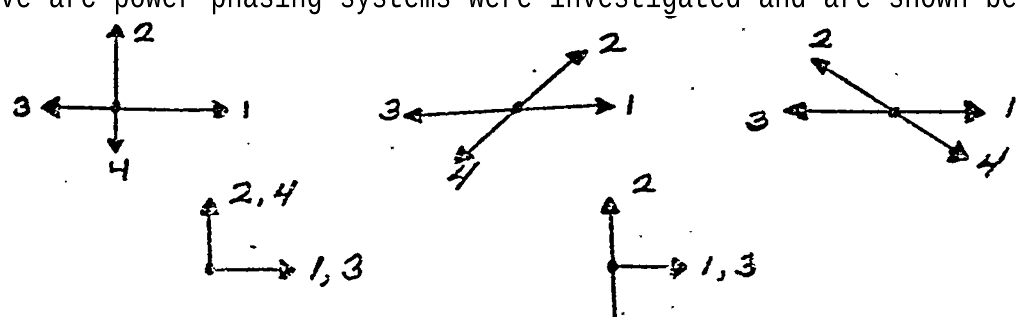
Weld No. 977-39B was made in 1" ABS Grade B plate prepared with double "V" type joint. **Employing welding amperages of 1300, 1400, 1200, and 1200 for electrodes 1, 2, 3, 4 respectively** a travel speed of 40 ipm was achieved.

Although stable amperage and voltage recordings were achieved, the top side weld result was high, narrow, and somewhat irregular. This result is similar to that achieved with the double Scott connection, system 4D.

With the assistance of two engineers from Bethlehem Steel Shipyard, Sparrows point, Maryland, a several-day evaluation of four electrode parameters previously evaluated at the shipyard was carried out. The weld results from this series of experiments still were characterized by narrow, high and somewhat irregular top weld appearance. The overall weld results were similar with both experimental and foreign made fluxes.

To evaluate the arc action and the influence of interacting magnetic fields, a high speed motion picture analysis was conducted.

Five arc power phasing systems were investigated and are shown below:



To photograph the arcs the welding system was allowed to run out of flux in air. Because of the very high currents and large amount of molten metal the arc-metal interaction was very violent. This made identification of arc deflection angles and meaningful magnetic arc interaction investigation impossible. Although various arcs were observed oscillating at times, as expected, because of the weld puddle undulations many periods of arc outages were also observed. The random weld puddle undulations combined with the high arc power observed in the weld appearance. Since the 1st and 2nd electrode are closely spaced and operate on solid plate a fixed surface is available for uniform arc Operation.

It would then appear a three wire system would provide superior stability to a four wire system if the 3rd wire is spaced a sufficient amount so as to arc behind the point where the weld deposited by the 1st and 2nd electrodes has solidified. This would allow the 3rd electrode to operate on a uniform, non-undulating metal surface.

Initial evaluations of three wire system to establish welding parameters were carried out. Weld results to-date are superior to those achieved with four electrodes but at reduced weld speeds. For this initial work our known and tested three wire AC system employing Scott connected lead and middle electrodes with the trail electrode in phase with the lead was used. Additional phasing systems will be investigated.

Three wire welding parameters for 1, 1 1/2 and several other plate thicknesses will be finalized during the next and final program period.

Report No. 4

Project SP-1-1 Part 101
Contract No. l560-721-l510-S/02-3764-C
One Side Welding Flux Development

PROGRAM OBJECTIVE

Presently available domestic submerged arc welding fluxes do not have the proper operating characteristics to produce one side welds of acceptable quality in heavy plate in ship fabrication. These fluxes also do not provide adequate impact resistance in heavy welds.

The objective of this program is to produce a flux suitable for manufacturing in the United States which, in con-junction with the multi-wire system described in SP-1-1, Item 102, will provide satisfactory quality one side welds in plate thicknesses up to 1 1/2 inch. When combined with a suitable wire, the mechanical properties of the weld joints must meet all requirements for ABS grades of carbon steel.

FIRST THROUGH THIRD QUARTER ACHIEVEMENTS

As discussed in the first through third quarterly reports, the following major accomplishments were achieved:

1) A flux has been developed which is capable of producing one side welds in 1 inch thick and 1 l/2 inch thick plates by using multiple electrodes on a flux copper backing system.

2) Weld performance of the flux is comparable to a commercially established one side welding flux.

3) Welds have been made with two electrodes, three electrodes, and four electrodes using multi-powered AC systems. Good weld performance and bead shape have been obtained with two multi-powered AC electrodes. Arc stability and weld performance appears to be somewhat erratic using four electrodes which may be difficult to control under commercial fabrication conditions. With four electrodes, the flux provides excess weld metal which results in a high and narrow top bead contour. Suitable operability and bead shape are achieved with three electrodes. However, the arcs are more active and less stable as compared to two electrodes.

4) Welds made in 1 inch thick ABS Gd. B plate using two, three and four electrodes gave mechanical properties meeting Grade 3T type requirements. Welds in 1 1/2 inch thick plate gave mechanical properties meeting Grade 2T type requirements.

FOURTH QUARTER GOALS

1) Produce one-side welds in 1 inch, 1 1/4 inch and 1 1/2 inch thick plate with the final flux formula under three electrode welding conditions.

2) Obtain mechanical properties from the welds in ABS Grades B, C and EH steels.

3) Supply a test quantity (up to 500 lbs.) of the final flux to the Bethlehem Steel Corporation.

FULFILLMENT OF FOURTH QUARTER GOALS

1) The final flux selected is identified as flux No. 977-39B and contains approximately 32% iron powder. Commercially acceptable one-side welds have been produced with the developed flux in l inch, 1 1/4 inch and 1 1/2 inch thick plates.

2) The charpy V-notch values of welds made in 1 inch thick ABS Grade B plate generally meet Grade 3T requirements. Those in 1 1/2 inch thick ABS Grade C plate meet only Grade 2T requirements. The values obtained from welds made in 1 1/4 inch thick ABS Grade EH-36 plate meet H-3 type requirements.

3) A test quantity of 500 lbs. of flux No. 977-39B has been submitted to the Bethlehem Steel Corporation, Sparrows Point, Maryland.

4) Additional development of the flux continued during the fourth quarter in order to obtain an improvement in the weld metal notch toughness values. Substitution of an iron powder containing law amounts of manganese and silicon for the non-deoxidized iron powder in flux 977-39B gave an improvement in the weld metal notch toughness values. Weld metal mechanical properties obtained with this flux (No. 977-43A) are reported and are compared with those obtained with flux 977-39B.

DISCUSSION

The flux selected for the final welds is identified as No. 977-39B. The chemical composition of the flux is shown in Table I and it contains approximately 32% iron powder. Its selection was based primarily on its capability of producing the best overall weld appearance in the three thicknesses, of plate investigated under a three electrode welding system. Higher and lower levels of iron powder in the flux were investigated during the development period and although the foreign commercial flux was found to contain 47% iron powder, this level resulted in excessive weld reinforcement under three electrode conditions. Satisfactory bead shape, however, was obtained under two electrode welding conditions with a flux containing 44% iron powder. These results were reported in the first quarter progress report.

The welding characteristics of flux 977-39B in general are similar to the foreign flux. The fused slag peels easily from both the top and bottom side of the weld deposit. Peeling on the bottom side of-the weld however is considered slightly superior to the foreign flux. Adequate peeling from the top of the weld is largely dependent upon the attainment of flat type bead shape. The flux outgases during welding due to the decomposition of calcium carbonate which is a major constituent in the flux. This outgasing also occurs with the foreign flux and it is similar to that which occurs with basic type coated electrodes except that the level is greater because of the higher amperages that are used. The calcium carbonate functions as an arc stabilizer and is considered essential in the particular formulation for high amperage multiwire weld performance.

Major accomplishments during this reporting period were the establishment of welding conditions to produce satisfactorily shaped welds in 1 1/2 inch and 1 1/4 inch thick plate as well as the attainment of mechanical properties which meet the welding requirements, for Grade EH steel.

The photographs in Figures 3 and 3A show two welds made in 1 1/2 inch ABS Grade C plate with fluxes 977-39B and 977-43A under identical three wire welding conditions.

The fluxes contain the same constituents with the exception of the type of iron powder. The iron powder used in flux 977-39B is a non-deoxidized type which has been used in all previously reported experimental fluxes. The iron powder used in flux 977-43A has a higher carbon level and contains residual manganese and silicon. Table II lists the typical chemical analysis of the two iron powders. Both types are commonly used by coated electrode manufacturers in the formulation of iron powder coated electrodes. Since the iron powder in the developed flux is the largest single constituent and since it forms a significant part of the weld deposit, different types should influence the weld metal properties differently. For this reason this second flux was investigated.

The crossections of the 1 1/2 inch welds show well shaped nuggets with symmetrical sides which are conducive to sound defect-free deposits. weld metal drop through on the bottom side is also sufficient and generally uniform along the length. The top of the welds are reasonably flat and exhibit adequate fill with good tie-in.

Similar appearing weld deposits were also obtained with the two fluxes in 1 1/4 inch thick ABS Grade EH-36 plate. Photographs 2 and 2A show the bottom, top and crossectional appearance of these welds.

The attainment of adequately shaped one side welds is dependent upon many variables including proper selection of welding conditions, wire spacing and wire diameters. For this series of welds, two 1/4 inch diameter wires were used for the middle and trail electrodes in conjunction with a 3/16 inch diameter wire for the lead electrode. The large diameter middle wire widens the center of weld nugget whereas the large size trail wire under high voltage conditions allows the top of the bead to flatten so that sufficient wash and tie-in are achieved. The use of the heavier diameter middle and trail electrodes are partially responsible for the improved bead shape in the 1 1/2 inch plate over the welds discussed in previous reports. Table III lists the welding conditions used for the welds described and additional details concerning other welding variables are discussed in the arc study section of this report.

The photographs in Figure 1 and 1A show the configuration and appearance of the welds made in 1 inch thick plate. With the heavier diameter wires, slower welding speeds had to be used as compared to those reported in the third quarterly report (25 ipm vs. 28 ipm). Even at the slower speed, bead shape and weld appearance are less-desirable because of excess reinforcement on top and slight Undercutting on the bottom. Figure 1B, from last quarter's report shows a much more desirable bead configuration.

In addition to the change in wire sizes and welding parameters, a higher manganese bearing middle electrode was used for all welds described in this report.

Mechanical properties of the 1 inch ABS Gd B plate welds are given in Tables IV and IVa. A considerable drop in the notch toughness values in the top section of the weld was obtained with flux 977-39B as compared to the values reported previously. (Weld No. 976-41 compared to weld No. 976-34 in third quarter report.) Whether this is due to the change in wire type, welding parameters or difference in base metal dilution is unclear. Comparison of the wled metal chemistry of the two welds does not offer an immediate explanation for the lower values. The impact values obtained with flux 977-43A which contained the manganese and silicon bearing iron powder showed an improvement *over* the comparison weld made with flux 977-39B (weld No. 976-411 compared to No. 976-41). The values are, however, about the same level as reported for weld No. 976-34 in the third quarter report. These meet 3 T Grade requirements which are 33 ft. lbs. charpy V-notch at +14°F.

The mechanical properties of the welds made in 1 1/4 inch EH-36 plate with both fluxes meet the H-3 Grade (20 ft. lbs. at -22°F.) requirements. (Tables V and Va) The impact properties from the two welds are very close but a slight preference is indicated for flux 977-43A.

Welds in 1 1/2 inch thick ABS Gd C plate meet only Grade 2T (25 ft. lbs. at +32°F.) properties (Tables VI and Via). A definite improvement in the notch toughness values however is apparent in weld made with flux 977-43A.

The 500 lb. test quantity of the flux which was shipped to Bethlehem Steel for fulfillment of this program was flux 977-39B. The mechanical property data concerning flux 977-43A became available several weeks after the flux had been processed and shipped.

TABLE I

FLUX COMPOSITIONS*

Flux 977-39B

Component	Percent
Iron	32.11
MgO	21.62
SiO_2	15.75
$CaCO_3$	10.63
CaO	1.45
Al_2O_3	3.74
CaF_2	3.98
Mn	4.57
Si	2.18
Na_2O	3.13
K_2O	0.80

*Flux 977-43A same as above except different type iron powder.

TABLE II

TYPICAL ANALYSIS OF IRON POWDERS

	Iron Powder in Flux 977-39B	Iron Powder in Flux 977-43A
C	0.04	0.08
S	0.015	0.02
Mn	0.015	0.40
Si	0.004	0.10
P	0.01	0.02
Fe	Bal	Bal
Apparent Density	3.45 g/cc	3.40 g/cc

TABLE III

WELDING CONDITIONS

Plate	1" ABS Gd. B		1 1/4" ABS EH-36		1 1/2" ABS Gd. C	
Weld No.s.	976-41	976-411	976-43	976-42	976-401	977-381
Fluxes	977-39B	977-43A	977-39B	977-43A	977-39B	977-43A
Wires	1 Linde 80, 3/16" 2 Linde 36, 1/4"		1 Linde 80, 3/16" 2 Linde 36, 1/4"		1 Linde 80, 3/16" 2 Linde 36, 1/4"	
Electrode 1						
Amps AC	1500		1500		1475	
Volts	36		38		37	
Electrode 2						
Amps AC	1075		1150		1100	
Volts	44		44		42	
Electrode 3						
Amps AC	1175		1250		1200	
Volts	49		49		49	
Travel Speed ipm	25		25		17.5	

TABLE IV

MECHANICAL PROPERTIES

Weld No. 976-41

Flux 977-39B

Plate - ABS Gd. B. - 1 in. thick

3 Electrodes

Welding Speed - 25 ipm

IMPACT PROPERTIES

	Top of Weld			Bottom of Weld		
Temp. %F	CVN Ft-Lbs.	Lateral Expansion (Mils)	% Shear	CVN Ft-Lbs.	Lateral Expansion (Mils)	% She
+72	45	40	43	75	66	70
+32	25	30	27	47	46	50
+14	20	20	20	44	39	40
-4	12	20	14	32	32	30
-20	9	10	9	31	30	30
-40	8	10	7	25	24	20

ALL WELD METAL TENSILE PROPERTIES (0.505)

UTS (psi)	71,500
YS (psi)	59,200
Elongation (%)	26.9
Reduction of Area %	61.1

TABLE IVa

MECHANICAL PROPERTIES

Weld No. 976-411

Flux 977-43A

Plate - ABS Gd. B. - 1 in. thick

3 Electrodes

Welding Speed - 25 ipm

IMPACT PROPERTIES

	Top of Weld			Bottom of Weld		
Temp. %F	CVN Ft-Lbs.	Lateral Expansion (Mils)	% Shear	CVN Ft-Lbs.	Lateral Expansion (Mils)	% Shear
+72	68	65	80	72	67	90
+32	58	57	70	53	48	70
+14	49	52	60	46	46	40
-4	34	37	50	40	43	30
-20	29	36	40	30	30	30
-40	25	25	20	21	22	20

ALL WELD METAL TENSILE PROPERTIES (0.505)

UTS (psi)	74,900
YS (psi)	54,300
Elongation (%)	30.3
Reduction of Area %	60.6

TABLE V

MECHANICAL PROPERTIES

Weld No. 976-43

Flux 977-39B

Plate - ABS Gd. EH-36 - 1 1/4 in. thick

3 Electrodes

Welding Speed - 25 ipm

IMPACT PROPERTIES

	Top of Weld			Bottom of Weld		
Temp. °F	CVN Ft-Lbs.	Lateral Expansion (Mils)	% Shear	CVN Ft-Lbs.	Lateral Expansion (Mils)	% Shear
+72	44	44	50	44	46	40
+32	25	27	30	31	30	30
+14	25	25	30	30	25	30
-4	24	23	30	21	21	20
-20	25	25	30	24	20	20
-40	19	17	20	12	10	10

ALL WELD METAL TENSILE PROPERTIES (0.505)

UTS (psi)	95,400
YS (psi)	73,900
Elongation (%)	21
Reduction of Area %	41.6

TABLE Va

MECHANICAL PROPERTIES

Weld No. 976-42

Flux 977-43A

Plate - ABS Gd. EH-36 - 1 1/4 in. thick

3 Electrodes

Welding Speed - 25 ipm

IMPACT PROPERTIES

	Top of Weld			Bottom of Weld		
Temp. %F	CVN Ft-Lbs.	Lateral Expansion (Mils)	% Shear	CVN Ft-Lbs.	Lateral Expansion (Mils)	% Shear
+72	56	53	50	45	45	50
+32	36	35	40	28	27	30
+14	33	32	40	23	18	20
-4	25	25	30	26	22	30
-20	22	22	20	22	21	20
-40	13	12	20	15	17	20

ALL WELD METAL TENSILE PROPERTIES (0.505)

UTS (psi)	93,100
YS (psi)	72,500
Elongation (%)	24.0
Reduction of Area %	53.2

TABLE VI

MECHANICAL PROPERTIES

Weld No. 976-401

Flux 977-39B

Plate - ABS Gd. C. - 1 1/2 in. thick

3 Electrodes

Welding Speed - 17.5 ipm

IMPACT PROPERTIES

	Top of Weld			Bottom of Weld		
Temp. °F	CVN Ft-Lbs.	Lateral Expansion (Mils)	% Shear	CVN Ft-Lbs.	Lateral Expansion (Mils)	% Shear
+72	30	32	30	52	47	50
+32	25	24	20	32	33	40
+14	12	12	20	25	26	30
-4	11	10	10	26	27	30
-20	11	10	10	12	13	20
-40	8	8	10	10	10	10

ALL WELD METAL TENSILE PROPERTIES (0.505)

UTS (psi)	87,200
YS (psi)	64,400
Elongation (%)	26.5
Reduction of Area %	56.6

TABLE VIa

MECHANICAL PROPERTIES

Weld No. 976-381

Flux 977-43A

Plate - ABS Gd. C. - 1 1/2 in. thick

3 Electrodes

Welding Speed - 17.5 ipm

IMPACT PROPERTIES

	Top of Weld			Bottom of Weld		
Temp. %F	CVN Ft-Lbs.	Lateral Expansion (Mils)	% Shear	CVN Ft-Lbs.	Lateral Expansion (Mils)	% Shear
+72	48	49	50	49	43	40
+32	30	30	30	32	34	40
+14	21	23	30	25	25	30
-4	13	12	20	20	23	20
-20	8	9	10	16	16	10
-40	5	6	10	9	7	10

ALL WELD METAL TENSILE PROPERTIES (0.505)

UTS (psi)	81,200
YS (psi)	59,400
Elongation (%)	28.4
Reduction of Area %	62.4

TABLE VII

WELD METAL ANALYSIS

Flux 977-39B

	Weld 976-41 1" ABS Gd. B	Weld 976-43 1 1/4" ABS EH-36	Weld 976-401 1 1/2" ABS Gd. C
C	0.14	0.17	0.15
S	0.017	0.022	0.012
P	0.011	0.010	0.012
Mn	1.70	1.70	1.55
Si	0.31	0.39	0.44
Ni	0.020	0.17	0.17
Cr	0.032	0.12	0.033
Mo	0.020	0.051	0.020
Cu	0.051	0.050	0.050
V	0.003	0.005	0.003
Ti	0.003	0.003	0.003
Zr	0.004	0.004	0.004
Al	0.005	0.011	0.017
Cb	0.005	0.005	0.005
Pb	0.002	0.002	0.002

TABLE VIIa

WELD METAL ANALYSIS

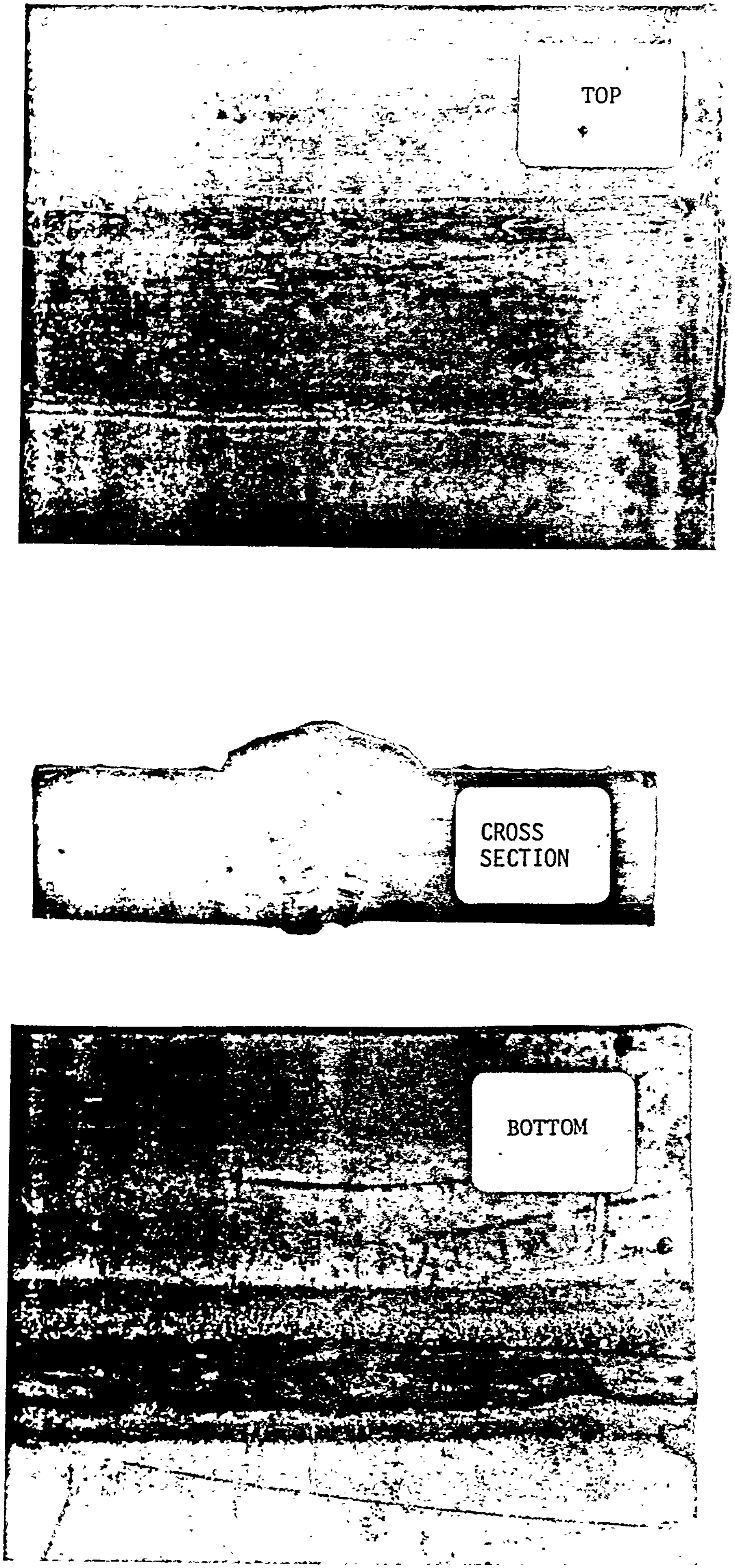
Flux 977-43A

	Weld 976-411 1" ABS Gd. B	Weld 976-42 1 1/4" ABS EH-36	Weld 976-381 1 1/2" ABS Gd. C
C	0.16	0.15	0.16
S	0.017	0.022	0.012
P	0.011	0.013	0.013
Mn	1.40	1.70	1.59
Si	0.20	0.34	0.38
Ni	0.022	0.020	0.024
Cr	0.028	0.13	0.034
Mo	0.18	0.050	0.020
Cu	0.048	0.047	0.056
V	0.002	0.003	0.003
Ti	0.003	0.003	0.003
Zr	0.004	0.004	0.004
Al	0.005	0.016	0.013
Cb	0.005	0.005	0.005
Pb	0.002	0.002	0.002

TABLE VIII

CHEMICAL ANALYSIS OF PLATE

	ABS Gd. B 1 in. Thick	ABS EH-36 1 1/4 in. Thick	ABS Gd. C 1 1/2 in. Thick
C	0.20	0.19	0.21
S	0.031	0.028	0.022
P	0.010	0.009	0.015
Mn	1.03	1.26	0.72
Si	0.03	0.24	0.22
Cr	0.024	0.17	0.016
Mo	0.005	0.065	0.005
Cu	0.015	0.016	0.017
V	0.002	0.003	0.002
Zr	0.005	0.005	0.005
Ti	0.002	0.003	0.003
Al	0.005	0.060	0.052
Cb	0.005	0.005	0.005
Co	0.01	----	0.01
Sn	0.02	----	0.02
Pb	0.002	0.003	0.002



WELD NO. 976-41

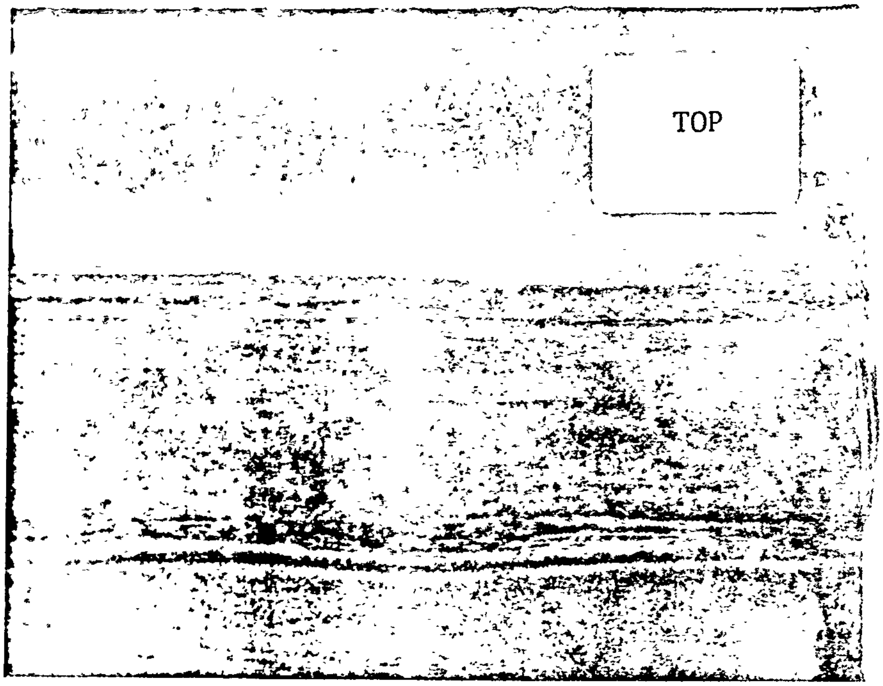
PLATE 1" THICK
ABS Gd. B

FLUX 977-39B

THREE WIRE

25 IPM

FIGURE 1



WELD NO. 976-411

PLATE 1" THICK
ABS Gd. B

FLUX 977-43A

THREE WIRE

25 IPM

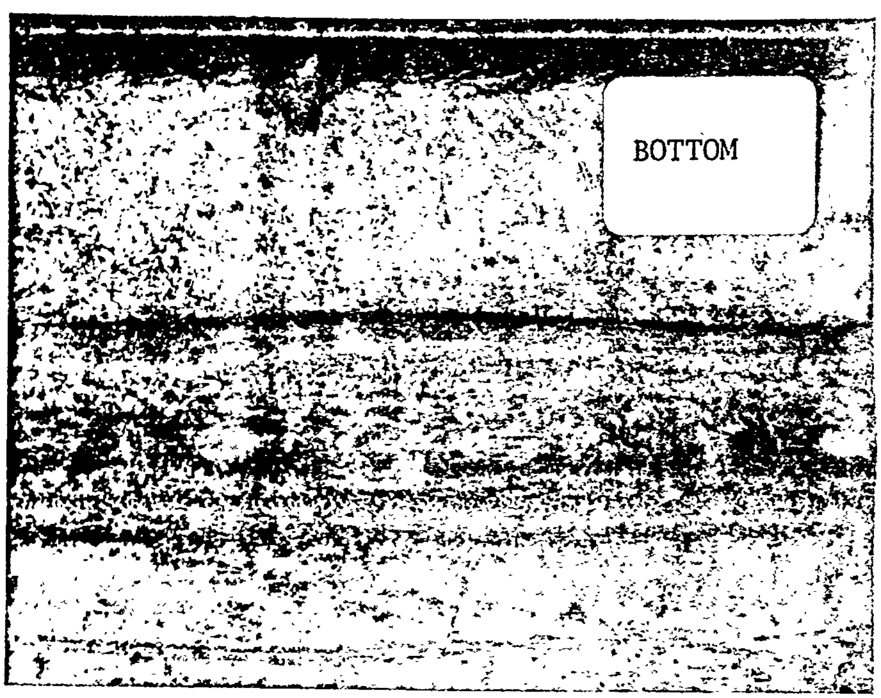
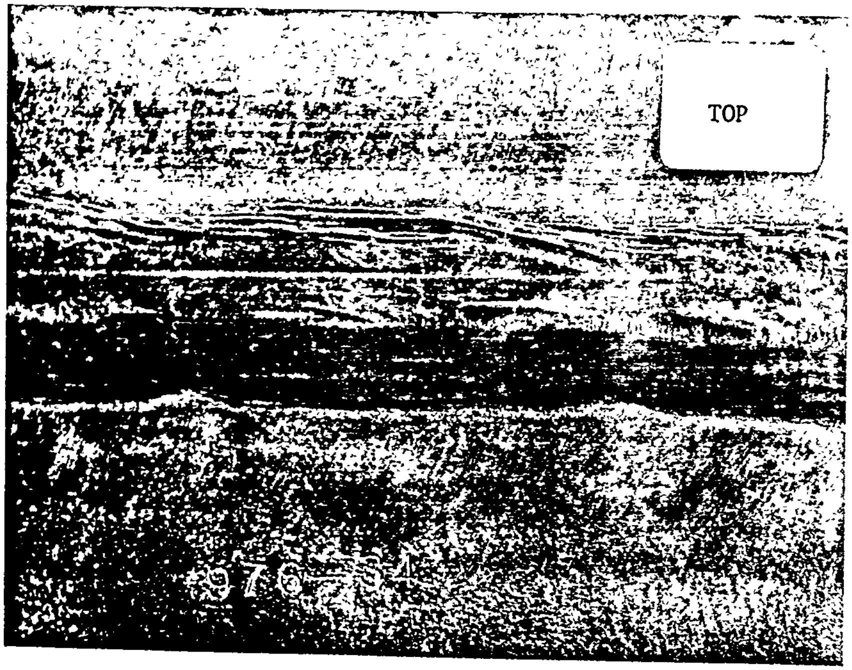
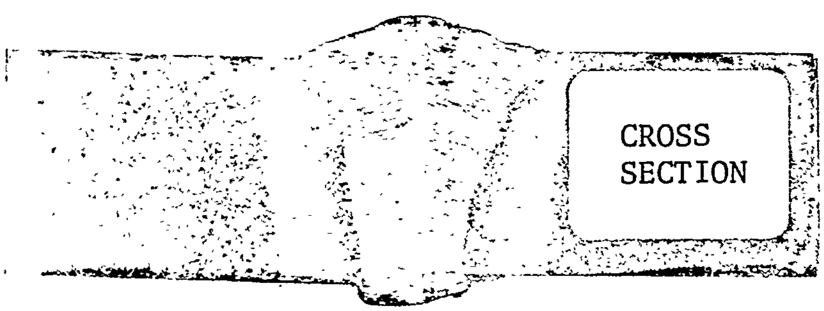
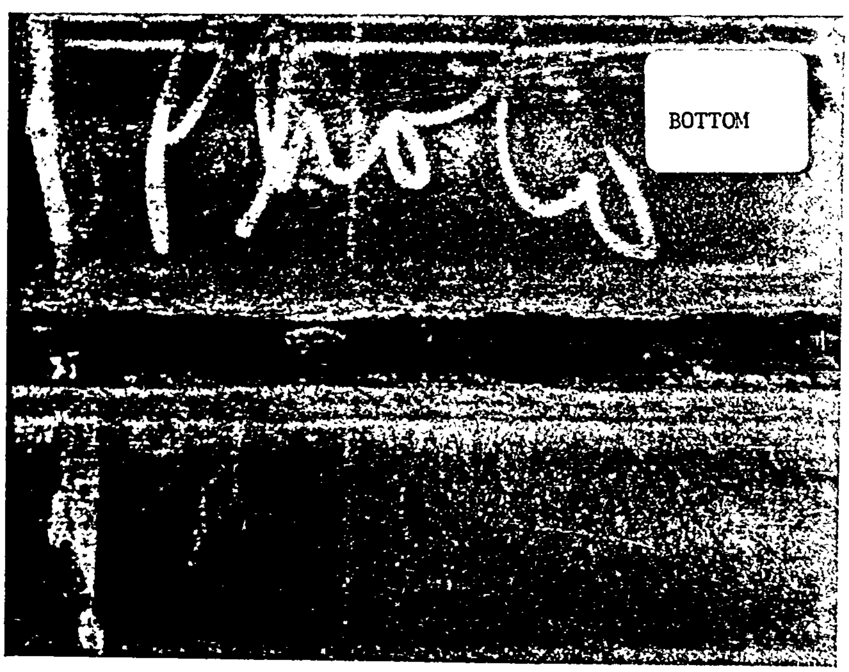


FIGURE 1A







WELD NO. 976-34

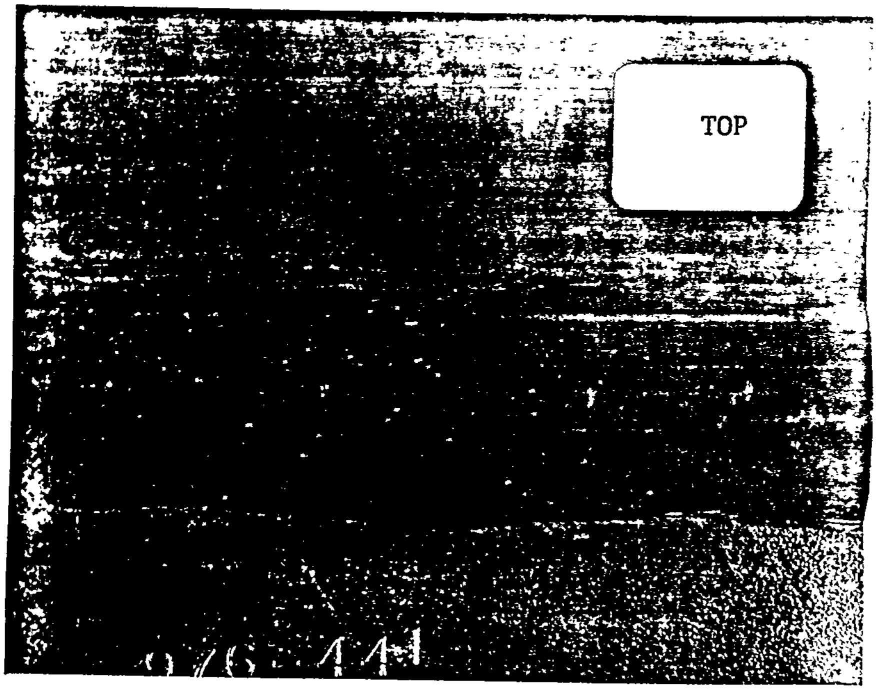
PLATE 1" THICK
ABS Gd. B

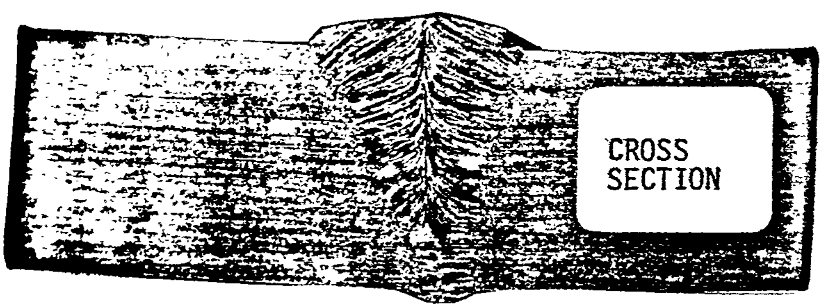
FLUX 965-39B

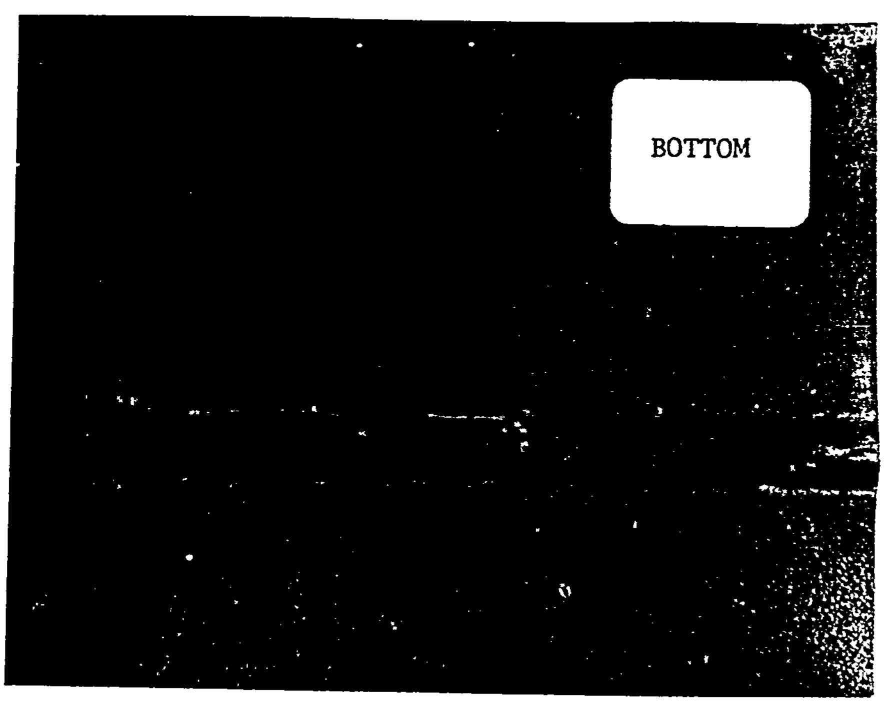
THREE WIRE

28 IPM

FIGURE 1B







WELD NO. 976-441

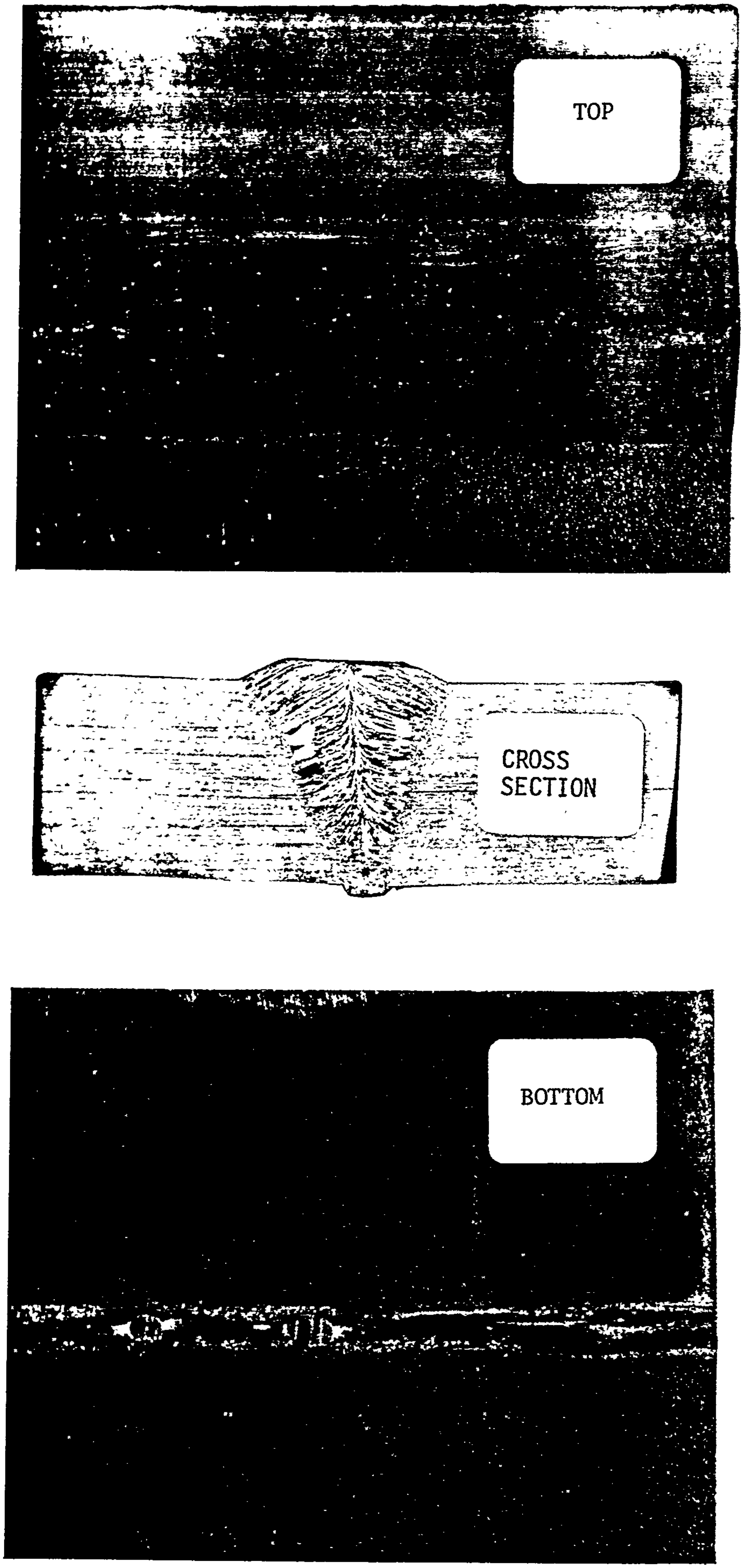
PLATE 1-1/4" THICK
ABS GD. EH-36

FLUX 977-39B

THREE WIRE

24 IPM

FIGURE 2



WELD NO. 976-42

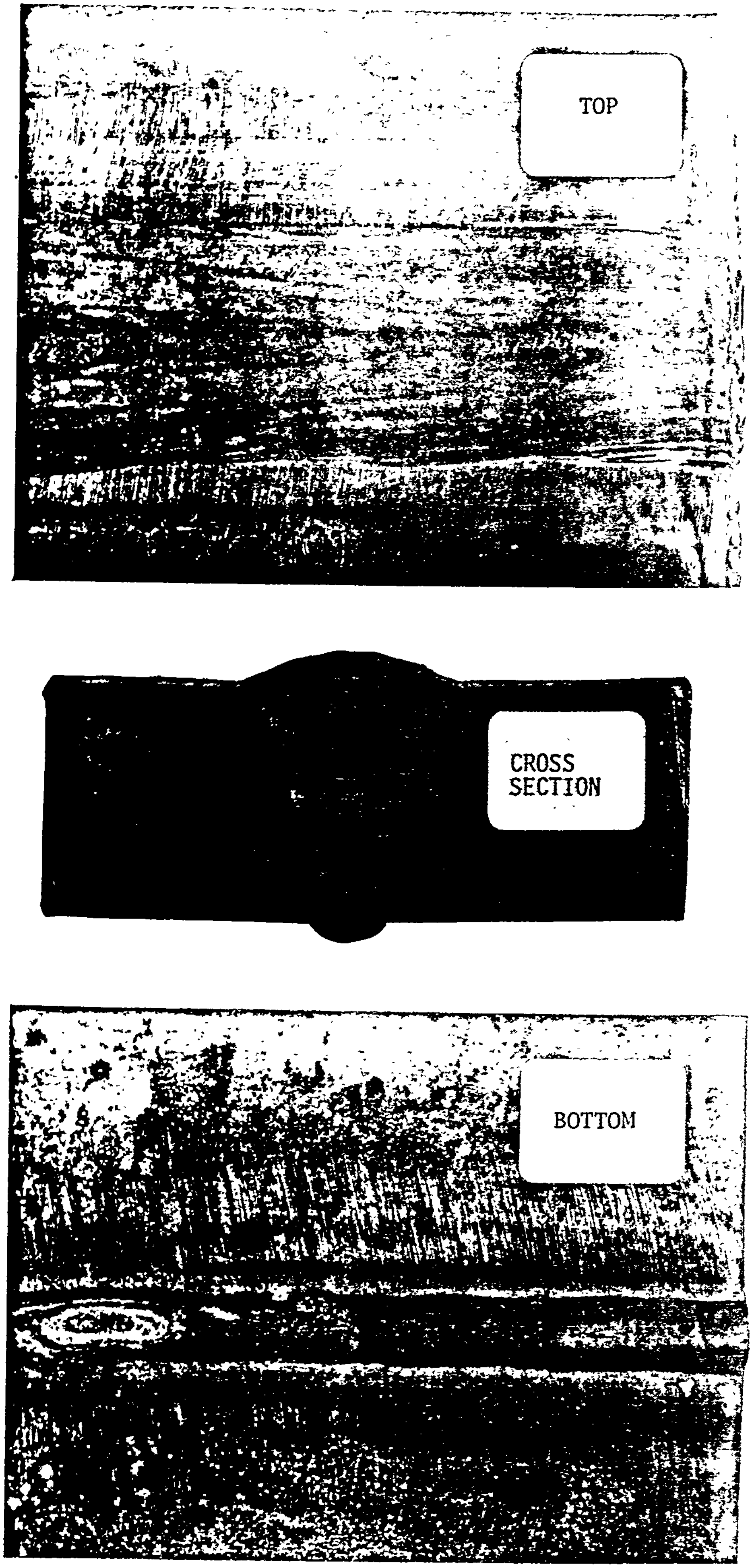
PLATE 1-1/4" THICK
ABS Gd. EH-36

FLUX 977-43A

THREE WIRE

24 IPM

FIGURE 2A



WELD NO. 976-401

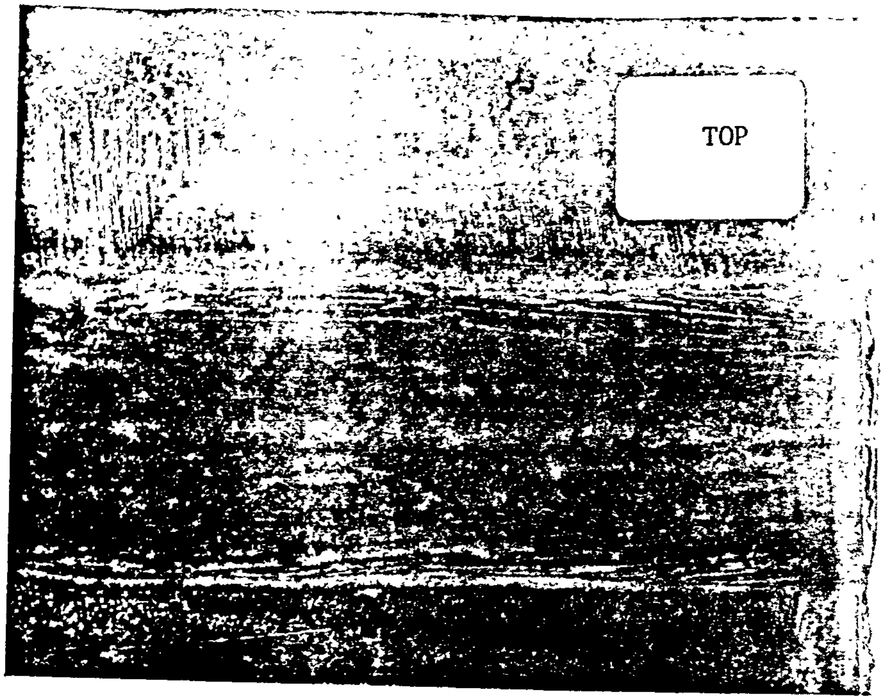
PLATE 1-1/2" THICK
ABS Gd. C

FLUX 977-39B

THREE WIRE

17.5 IPM

FIGURE 3



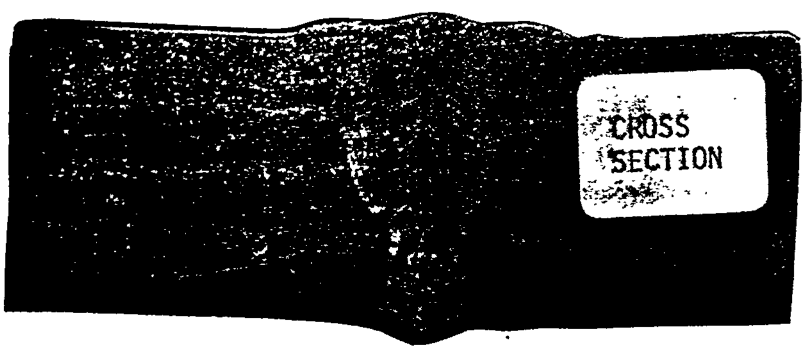
WELD NO. 976-381

PLATE 1-1/2" THICK
ABS Gd. C

FLUX 977-43A

THREE WIRE

17.5 IPM



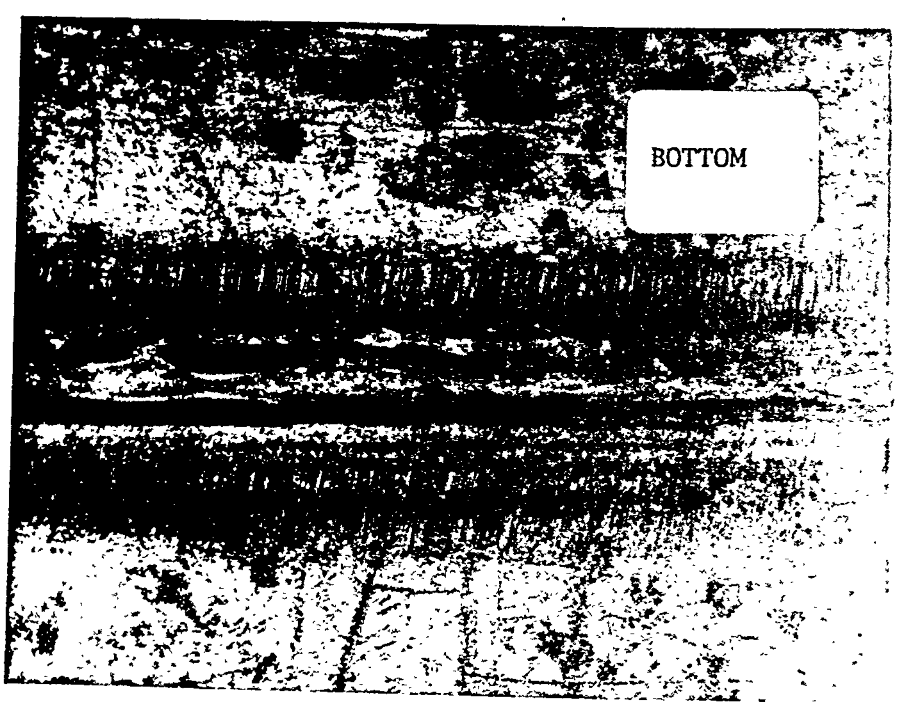


FIGURE 3A

Report No. 4

Project SP-1-1 Part 102
Contract No. 1560-721-1511-S/02-3764-D
One Side Welding Multiple Arc Study

PROGRAM OBJECTIVES

To provide sufficiently high travel speeds for economical one-side welding, a multi-electrode submerged arc system is necessary.

The initial program goal was to develop a four electrode welding system to achieve a welding rate of 25 to 30 ipm for 1 1/2 inch thick plate material. Work with the four electrode system indicated an excess of metal and difficulty with weld reinforcement control were major obstacles to achieving successful results.

It was agreed the program goals would be shifted to achieving maximum weld speeds and quality with a three electrode system. The weld speed goal was changed to achieving 25 to 30 ipm for 1" thick plate.

FIRST THROUGH THIRD QUARTER ACHIEVEMENTS

As covered in the First through Third Quarter reports, several major goals were accomplished:

1) After assembling the welding equipment, a theoretical arc deflection analysis was conducted and completed. Of the sixteen separate variations of system parameters analyzed two were selected for further study.

2) One of the above power phasing systems (referred to as 4D; a pair of Scott connected electrodes followed by another Scott connected electrode pair 180 degrees out of phase with the lead pair) was used to make an extensive series of welds in 1" and 1 1/2" thick plates.

3) In the above series of experiments, weld speeds exceeding the initial goals were achieved. Weld bottom side results were satisfactory, however, top surface beads had excess reinforcement and were somewhat irregular.

4) Welds were made with the 120 degrees, 60 degrees, power phasing, system 3D. Weld results were similar to the double Scott 4D system and not totally satisfactory.

5) A high speed motion picture study of the four electrode system was conducted. Because of the very high currents and large amount of molten metal beneath the arcs, the arc-metal interaction was very violent. This made identification of the arc deflection angles and meaningful magnetic arc interaction investigations impossible.

6) Initial evaluations of a three wire system indicated satisfactory welds could be achieved at a slight reduction in speed over the four arc system.

FOURTH QUARTER GOALS

1) Investigate several three electrode AC phasing systems to determine the effect on weld performance.

2) Finalize three wire welding parameters for 1" and 1 1/2" thick plates.

FULFILLMENT OF FOURTH QUARTER GOALS

Several three wire power phasing systems were evaluated; two of which were given more extensive observations and one was selected for a final system. The final power phasing system selected utilizes a Scott connected lead pair of electrodes followed by a trail electrode connected in phase with the lead Scott electrode.

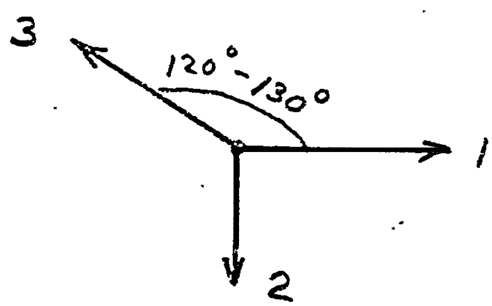
Final satisfactory procedures were developed with the above-mentioned power phasing system for 1", 1 1/4" and 1 1/2" thick plates. The specific results are outlined in the 1st section of this report.

A table listing the final parameters developed for these plate thicknesses and one covering the effect of variable changes are also provided. (See Table I and III)

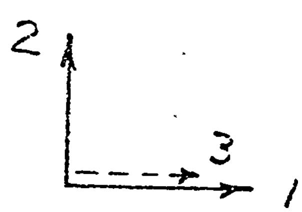
TECHNICAL DETAILS

From several three wire power phasing systems initially evaluated, two were selected for further study.

One system which is being used commercially abroad was approximated with the power phasing shown vectorially below:



The second system is one which is used for line pipe manufactured by many producers and is shown vectorially below:



Of the two systems, the latter provided a more stable third electrode condition and produced more uniform well shaped top side welds. It was, therefore, the system used to achieve the final welding parameters for the 1, 1 1/4 and 1 1/2 inch thick plates.

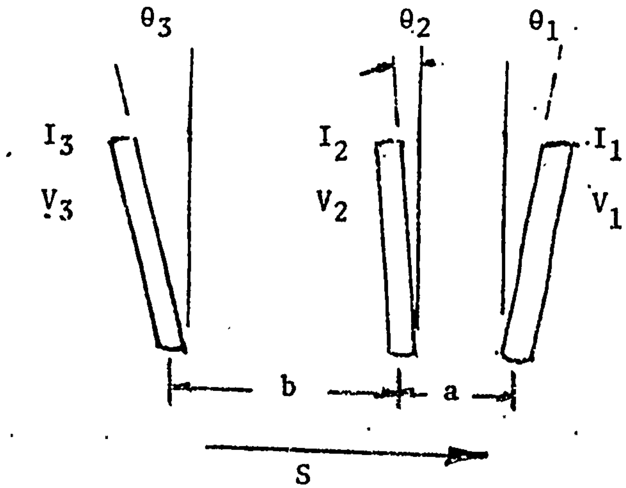
Final welding parameters were established for three thickness of plate. All welds were well shaped both top and bottom and possessed good nugget contours. The results of specific test plates are presented in the first section of this report.

From these specific conditions, a set of generalized parameters is presented in Table I. Table II presents the joint configurations to be utilized for these general parameters. In Table III, a description is provided to show what weld results can be expected from deviations from set procedures. This Table also presents some understanding of the effect of each electrode in the system.

Simply stated, the lead and middle electrode provide the desired penetration, underbead formation, and center-to-bottom nugget shape. The third electrode is positioned at a point after the underbead has formed and solidified and controls the final top side weld appearance and nugget shape. As noted, the welding currents are established to provide the proper penetration and weld shape. Welding voltage is generally quite high and is held under the level which would result in excessive flashing.

TABLE I

GENERAL PARAMETERS FOR 1", 1 1/4" and 1 1/2" PLATE



ELECTRODE CONFIGURATION

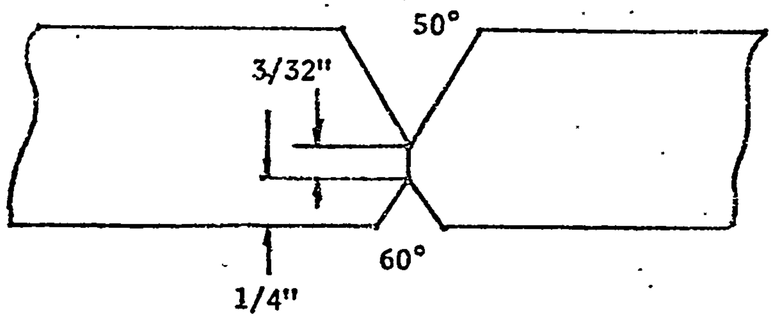
LEAD		MIDDLE			TRAIL		
θ_1	Diameter	a	θ_2	Diameter	b	θ	Diameter
0 to 5°	3/16"	1-1.5	10°-15°	1/4"	3.5-4"	10-15°	1/4"

WELDING PARAMETERS

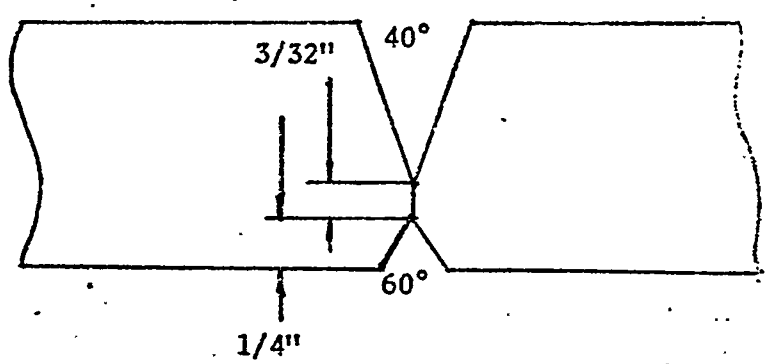
LEAD		MIDDLE		TRAIL		TRAVEL	
I_1 Amps AC	V_1 Volts	I_2 Amps AC	V_2 Volts	I_3 Amps AC	V_3 Volts	Plate	ipm
1475-1500	40-44	1075-1150	42-44	1175-1250	46-49	1"	25-28
						1 1/4"	23-24
						1 1/2"	19-22

TABLE II

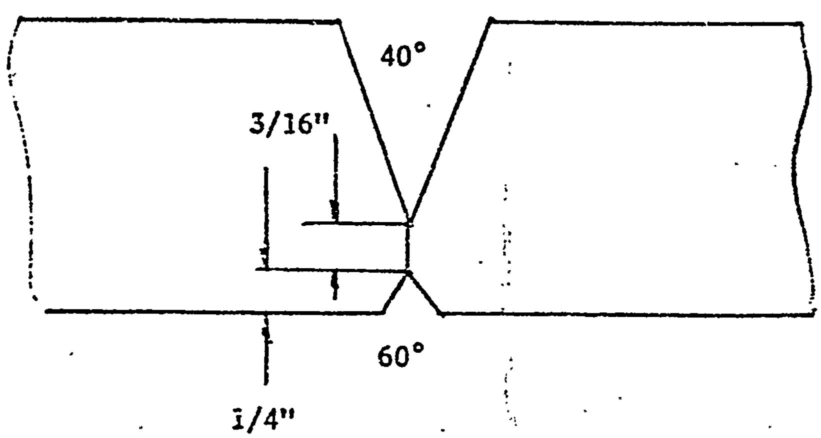
PLATE PREPARATION



1"



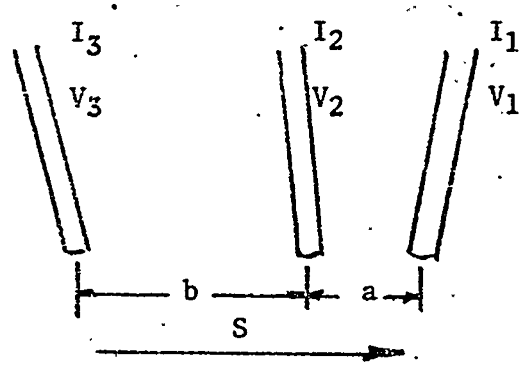
1 1/4"



1 1/2"

TABLE III

EFFECT OF PARAMETER VARIATIONS



PARAMETER	EFFECT OF INCREASING	EFFECT OF DECREASING
I_1	excessively wide underbead	narrow, irregular underbead
I_2	excessively wide underbead	narrow, irregular underbead
I_3	excessive reinforcement and flash through	rough surface and irregular square edges
V_1	excessive arc flash through	irregular underbead
V_2	excessive arc flash through	poor (too narrow) nugget shape
V_3	excessive arc flash through	narrow, irregular top surface
a	insufficient penetration	excessive arc action
b	poor top bead appearance	poor top appearance and arc action
S	insufficient fill	excessive reinforcement, insufficient underbead